METALS & ALLOYS

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The Magazine of Metallurgical Engineering

INCLUDING
CURRENT METALLURGICAL ABSTRACTS

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VOLUME 3

NUMBER 11

NOVEMBER 1932

$3.00 a Year

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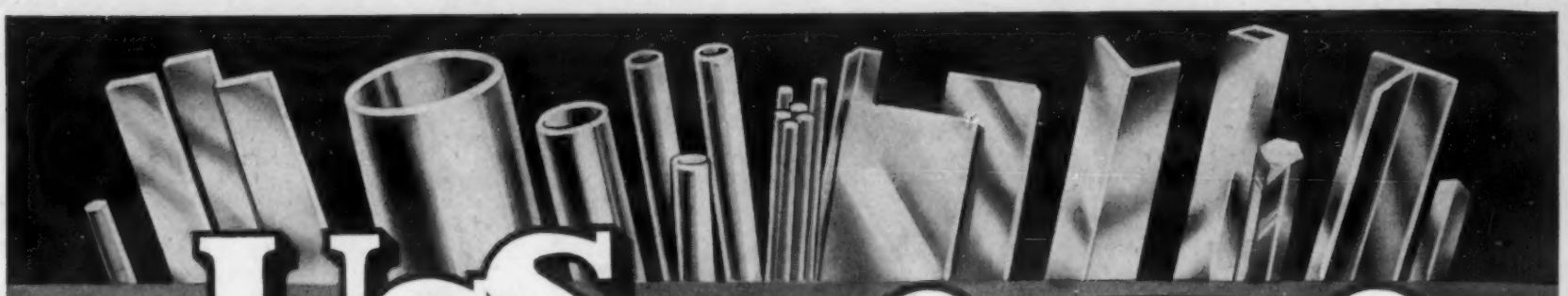

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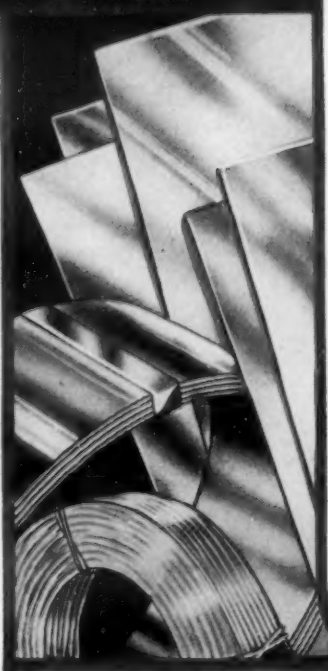

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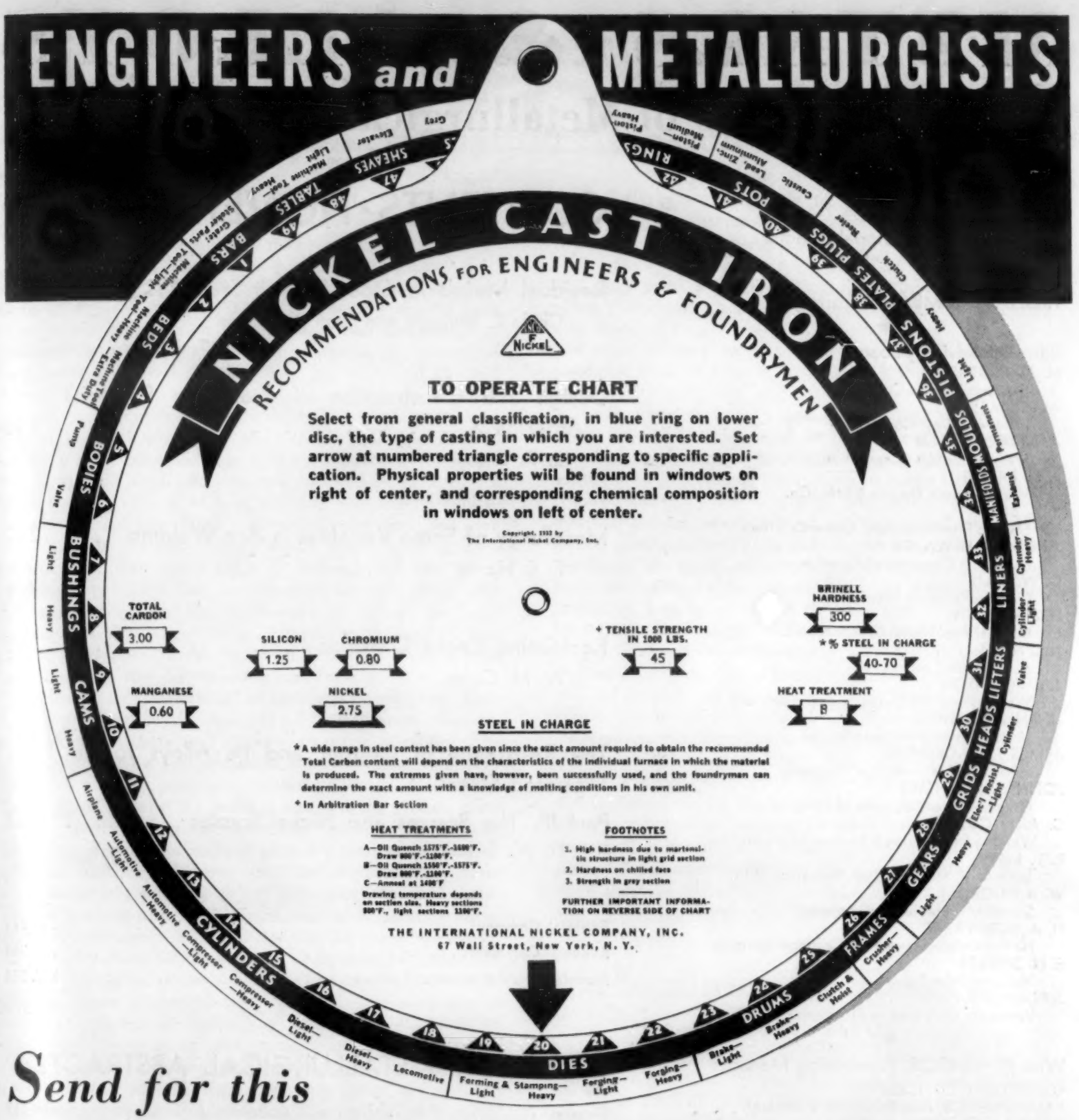

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The Magazine of Metallurgical Engineering

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PUBLISHED MONTHLY BY THE CHEMICAL CATALOG COMPANY, INC.
Ralph Reinhold, Pres.-Treas.
Philip H. Hubbard, Vice-Pres.
H. Burton Lowe, Vice-Pres.
Francis M. Turner, Vice-Pres.

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Annual Subscription: U. S., Possessions, Mexico and Cuba, $3.00; All Other Countries, $4.00. All communications relating to subscriptions or back issues should be addressed to METALS & ALLOYS, 3619 Forbes Street, Pittsburgh, Pa.

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Entered as second-class matter March 14, 1932, at the post office at Pittsburgh, Pa., under the Act of March 3, 1879.

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EDITORIAL COMMENT

Electroplating Research

ELECTROPLATED coatings may be very good or very bad, depending on thickness, adhesion, structure and freedom from pinholes. Up to quite recent years, plating has generally been an empirical, rule of thumb process, with little of standardization either as to process or product. There has been a woeful lack of scientific attention to the chemical and metallurgical fundamentals involved, in comparison to the potential usefulness of plated articles. The job plater of the old days did not have a sufficient volume of business to allow him to go very deeply into technical details for the improvement of any one of the various plating processes he carried on, nor was he, as a rule, educated well enough technically either to do research himself or to apply it when done by others. Hence, not only research on fundamentals to find new facts and explain old ones, but also education of platers so they could apply the research information, was necessary.

Plating research has been carried on first by a very few universities and by the Bureau of Standards, later by some of the larger firms, especially automobile and electrical manufacturers, much of the work having been published by the Electrochemical Society.

The equally important educational work has been largely fostered by the American Electroplaters' Society, through its Bulletin and its local chapter meetings. The other engineering and technical societies have paid very little attention to plating or plated products. Almost the first sign of interest by general engineering groups came very recently, when the American Society for Testing Materials decided to include plated products in its program of outdoor exposure tests for the study of corrosion resistance, with the object of finding out what thickness of coating and what plating methods produce satisfactory resistance. The preparation of these specimens was chiefly done at the Bureau of Standards under Dr. Blum, through a Research Associateship supported by the American Electroplaters' Society. The examination of these specimens and the correlation of the data by Dr. Blum's men, as originally contemplated in the plans for the project is one of the most important tasks imaginable in the plating field. The specimens are already under exposure, and to abandon the project now would be to lose the investment already put into the work.

Yet there is danger that the American Electroplaters Society may not be able to continue this work at the Bureau under Dr. Blum, which will require but $4,000 for the coming year, and the Society is asking those who make and use electroplated products to make certain its continuation, by financing the work. It is asking for no contribution larger than $25.00, since there are thousands of firms who will benefit from the work. Subscriptions are to be sent to Mr. Walter Fraine, 507 Grand Avenue, Dayton, Ohio, or to any of the officers of the Society or members of the Research Committee.

It seems to us that those firms whose plating departments have difficulty in getting deposits of the proper quality should readily see the value of the information that will come out of this work. But perhaps it is even more important to those who do produce uniformly good plating, that standards be set up to exclude poor plating and that the education of their competitors be fostered. An automobile door handle with the plating peeling and the handle corroding tends to discredit all plating in the eyes of the customer. The same thing runs through a wide variety of products. Plating of a decorative or corrosion-resistant metal over a cheaper or less resistant one is a very good way of making a cheaper product, provided the coating remains decorative and really resists corrosion.

Unless it does so, the customer will demand other products that cost more to make. If the maker uses a more costly material, and raises the price, the product will not have so wide a sale. If he does not raise the price, he cuts his margin of profit. Improving the quality of plated wares, and then maintaining that quality, is essential to low cost of production in many lines.

Even though some firm may feel that it knows what are the proper standards of plating practice and for plated products, and feels that it can anticipate the final results of the study, its own say-so will carry little credence compared to that carried by the findings of such impartial bodies as the A.S.T.M. and the Bureau of Standards. So it might well support the project in order to get the truth more promptly accepted as truth.

It will not do for industry to trust that the project will be carried out by the Bureau of Government funds, whether industry aids or not. The plating research of the Bureau on fundamental studies has already been supported by Government funds to a total many times that of the sum supplied by industry through the Research Associate plan. In these days the general tax payers' money will not be applied to projects of such definite commercial bearing that they should obviously be supported by industry. Hence, the Electroplaters' Society must look to industry for action to bring this worthy work to completion.—H. W. GILLETT

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Metallurgical Research Activities

AT THE suggestion of the Committee on Correlation of Research of the American Institute of Mining & Metallurgical Engineers data were collected by the U.S. Bureau of Mines on the research problems being studied by private corporations, university, institutional and government research laboratories in 1930-31. The results are summarized by Fieldner and Emery in U.S. Bureau of Mines Information Circular 6637.

The subjects covered are coal and its products; petroleum, natural gas and asphalt; other non-metallic minerals and products; and metallic ores and products. While there is much listed under fuels and refractories that is of interest to the metallurgist, we shall confine our comments to the purely metallurgical items, and since the circular can be obtained by writing the Bureau of Mines at Washington, we shall not re-catalog the items.

One notes first that, with some exceptions, most industrial corporations report but a few topics of research and couch these in very vague, broad and general terms. There is a vast deal of industrial research going on, even in these times, that is not reflected at all in this list. On the other hand, some educational institutions have listed far more than they can be doing on any intensive scale

(Continued on Page 254)

(Courtesy Andrews Steel Company, Inc.)

RESIDUAL METALS in

By CLYDE E. WILLIAMS*

Use of Steel Scrap in the Open-Hearth

IN OPEN-HEARTH steel the presence of residual metals that come from scrap has been a source of much concern to steel plant operators. Owing to the use in basic open-hearth charges of alloy-steel scrap, tinplate clippings, detinned, galvanized, and other coated scrap, and of non-ferrous metals that cannot be sorted from scrap economically, basic open-hearth steel has been increasing gradually in copper, chromium, nickel, tin, and vanadium contents. Some plants, dependent upon the use of large ratios of scrap high in some of these metals, have produced steel ingots of exceptionally high contents of some of these metals that have come entirely from the scrap used.

At times, difficulties in rolling the steel or in the working of the finished product have cast suspicion on some of these residual metals. At other times, improved qualities have been thought to result from the presence of one of these elements.

The curves in Figs. 1 and 2 have been plotted to show the variation in the amount of steel scrap used in different years and to permit comparison of this with prices and production rates. Figures for scrap consumption up to 1931 were obtained by calculation from the statements of basic pig iron and basic open-hearth steel production contained in the Annual Statistical Reports of the American Iron and Steel Institute and in Mineral Industry. For 1931 the basic open-hearth steel production was estimated by multiplying the published figure for total steel production, given in Mineral Market Reports No. M.M.S. 113, U. S. Bureau of Mines, by the ratio of the basic open-hearth to total steel production in 1930. Thus, this figure might not be exact. In determining the percentage of scrap used, it was assumed that (1) an ingot recovery of 88% of the metal charged was made, (2) metallic addition agents equivalent to 1% of the charge were used, and (3) iron ore containing 50% recoverable iron was used to the extent of 5% of the pig iron charged. Some of these figures were published by one of the authors in U. S. Bureau of Mines Technical Paper 418, Electric Furnace Cast Iron, by C. E. Williams and C. E. Sims, 1928.

The curves show that, whereas the percentage of scrap used in the basic open-hearth constantly decreased from 64% in 1901 to 44% in 1909, it gradually increased to 56% until 1922, after which it fluctuated between 49 and 54% until 1931, when it again increased to 59%. Many interesting deductions can be drawn from these curves, such as the effects of the price spread between scrap and pig iron, of the production rates, and of the changes in steel making methods. The important fact is that the general trend of the ratio of steel scrap to pig iron used in the basic open-hearth has been upward since 1908, in spite of the fact that over short periods of time decreased output of steel causes an increase in the percentage of scrap used, as is shown by comparing the figures for 1930 and 1931.

It is believed that results prior to 1908, which show a decreasing use of scrap, represent an unusual situation wherein an excessive amount of scrap was available, owing to the relatively large production of Bessemer steel and the undeveloped state of the nation's manufacturing industry. Hence, the period since 1908 is more normal. Automobile scrap has been increasing relatively to other scrap, owing to the increase in production and the short average life of automobiles. It seems safe to predict that,

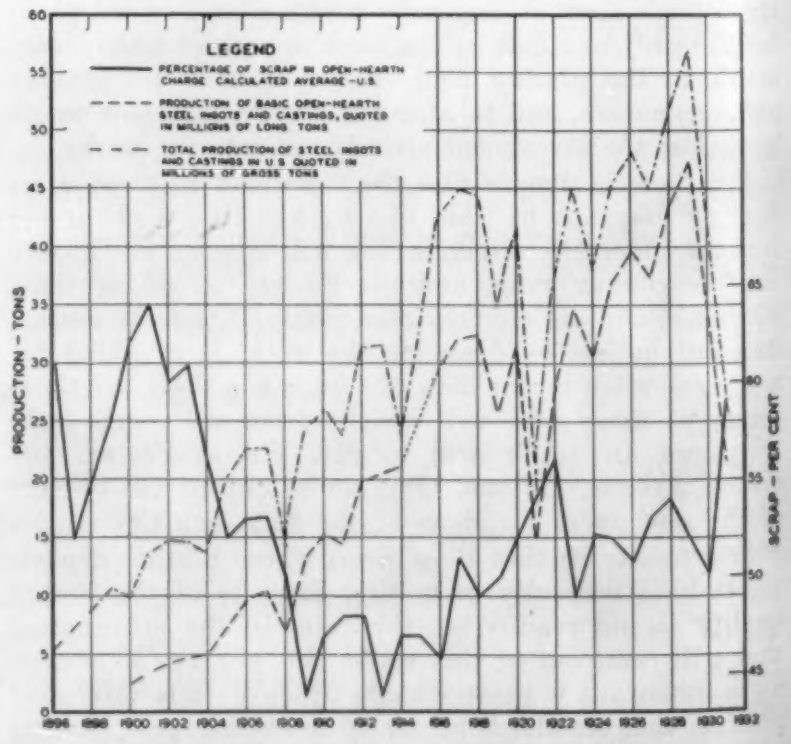
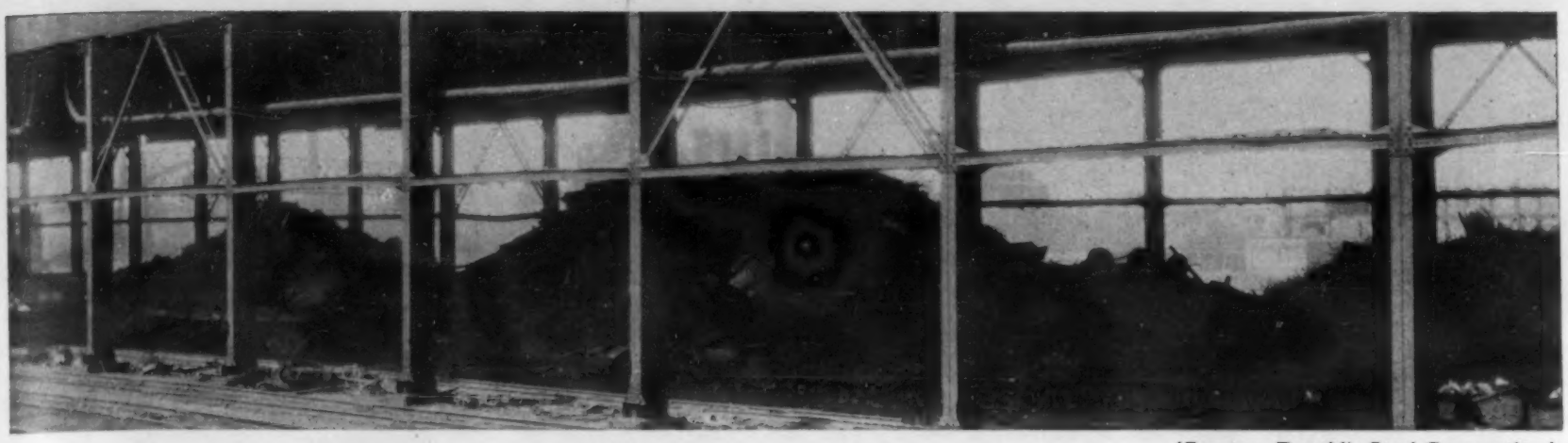

LEGEND
PERCENTAGE OF SCRAP IN OPEN-HEARTH CHARGE CALCULATED AVERAGE - U.S.
PRODUCTION OF BASIC OPEN-HEARTH STEEL INGOTS AND CASTINGS, QUOTED IN MILLIONS OF LONG TONS
TOTAL PRODUCTION OF STEEL INGOTS AND CASTINGS IN U.S. QUOTED IN MILLIONS OF GROSS TONS
PRODUCTION - TONS
SCRAP - PER CENT

Fig. 1. Relation Between Amount of Scrap Used in Basic Open-Hearth and Production of Basic Open-Hearth and Total Steel.

*Battelle Memorial Institute, Columbus, Ohio.



(Courtesy Republic Steel Corporation.)

in OPEN-HEARTH STEEL

and JOHN D. SULLIVAN*

for a long time to come, the ratio of scrap to pig iron used will not differ greatly from that existing in the past 10 to 15 years. Moreover, increasing amounts of scrap are being used in the blast furnace for making basic pig iron.

Most of the foreign metals introduced into the basic open-hearth charge through the scrap used are partly or wholly recovered in the steel. Copper, nickel, and tin are wholly recovered. Although copper may be readily oxidized, its oxide is reduced by iron and under the conditions existing in the open-hearth metallic copper may be introduced into steel from the oxide. Tin in a bath of steel cannot easily be oxidized and slagged off,[1] and its boiling point is far above the operating temperature of the open-hearth. Most of the vanadium is recovered in the steel; in fact, vanadium has been introduced to steel by the addition of the oxide. Much of the molybdenum in the charge is recovered. Although definite information is not available as to the percentage of recovery of chromium, when various amounts are present in the charge some of it is always recovered. Although zinc boils below steel-making temperatures and most of it is lost, some zinc always seems to remain in the steel. Lead is largely lost either by seepage into the furnace bottom or by vaporization.

[1]C. E. Williams, C. E. Sims and C. A. Newhall. Detinning and Production of Synthetic Gray Iron from Tin Plate Scrap. *Electrochemical Society Transactions*, Vol. 43, 1923, pages 191-202.

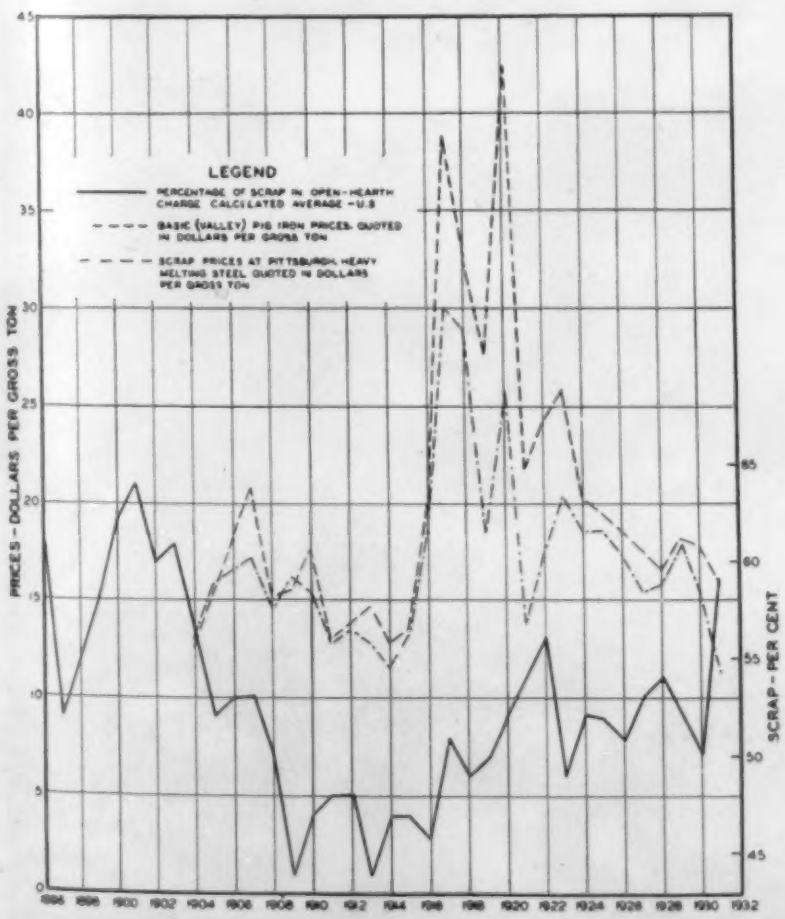


Fig. 2. Relation Between Amount of Scrap Used in Basic Open-Hearth and Prices of Basic Pig Iron and Steel Ingots.

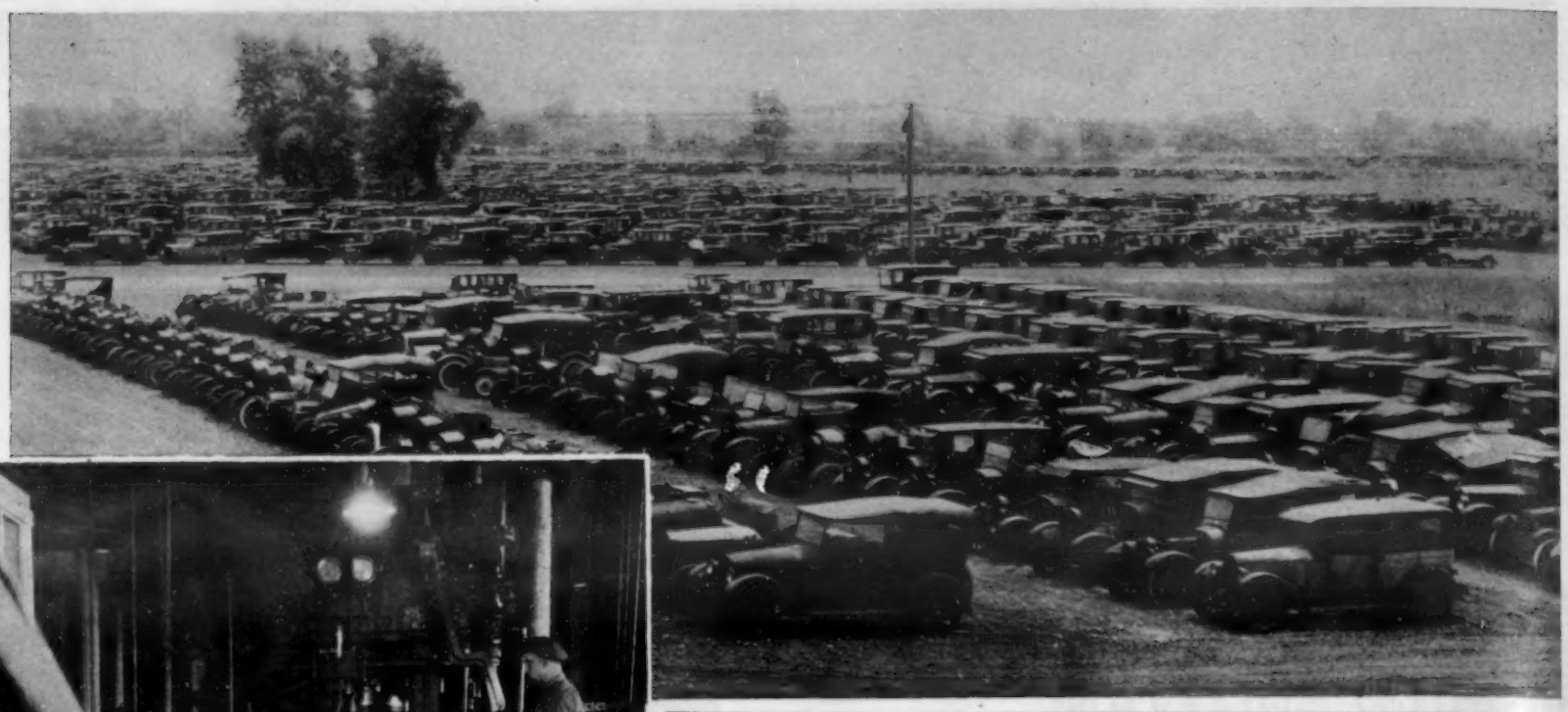
Residual Metals in Finished Steel

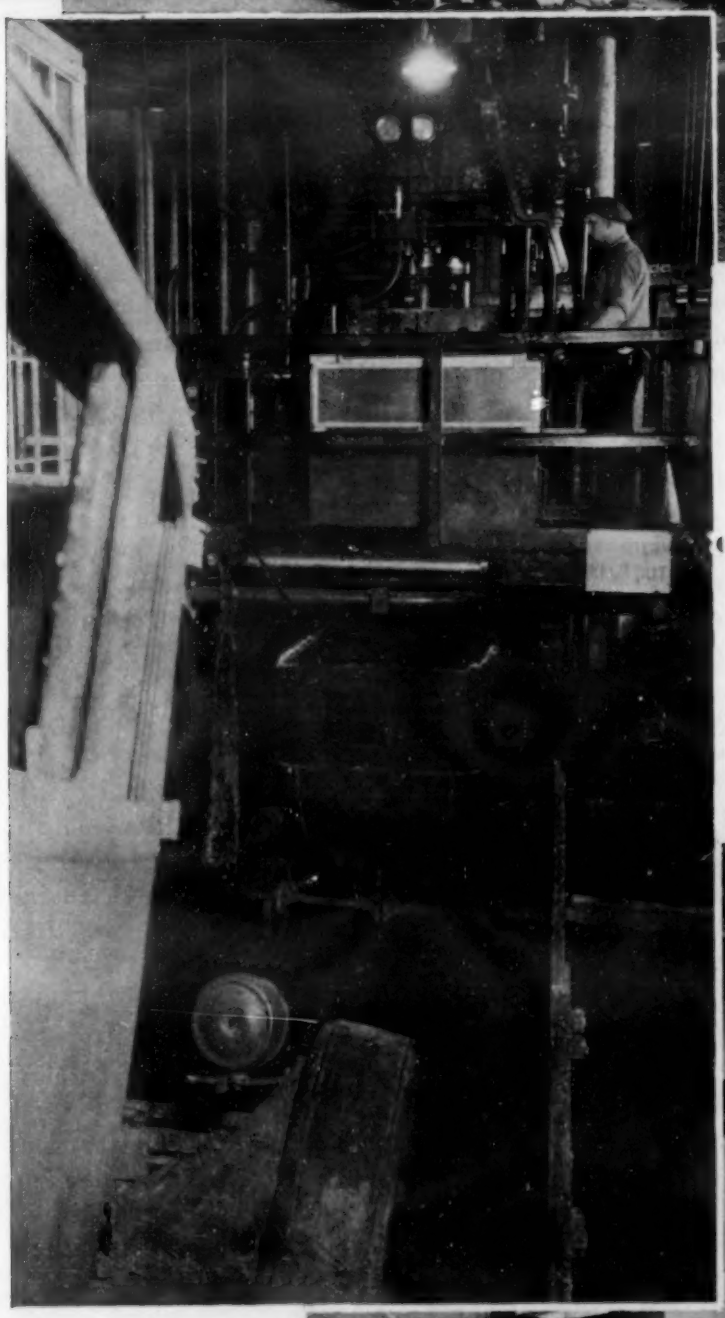
Thus, it is evident that these residual metals will increase in open-hearth steel as increasing amounts of alloyed and coated steel are made and returned as scrap. It is important, therefore, to know the amounts of these metals present in steel, the rate at which they are increasing, and their effects on the manufacture and use of the finished steel.

In November 1929, the Open-Hearth Committee of the American Institute of Mining and Metallurgical Engineers instituted a plan to determine the content of foreign residual metals in basic open-hearth steel. Since then from 12 to 21 companies, located in various parts of the United States and Canada, have been taking samples for analysis. The samples are taken from representative heats before alloy additions are made. Thus, the analyses represent the residual metals. At the end of the month, composite samples of these are made, from which either quarterly or semi-annual composites are made for analyses. At present, 18 steel companies, which represent a normal annual capacity of 8,500,000 tons, are submitting samples.

Analyses were made at the Pittsburgh Station of the U. S. Bureau of Mines until March, 1931. These are reported in the Minutes of the Open-Hearth Committee, A.I.M.E., published in 1930 and 1931. Since then analyses have been made at Battelle Memorial Institute; these results are given below.

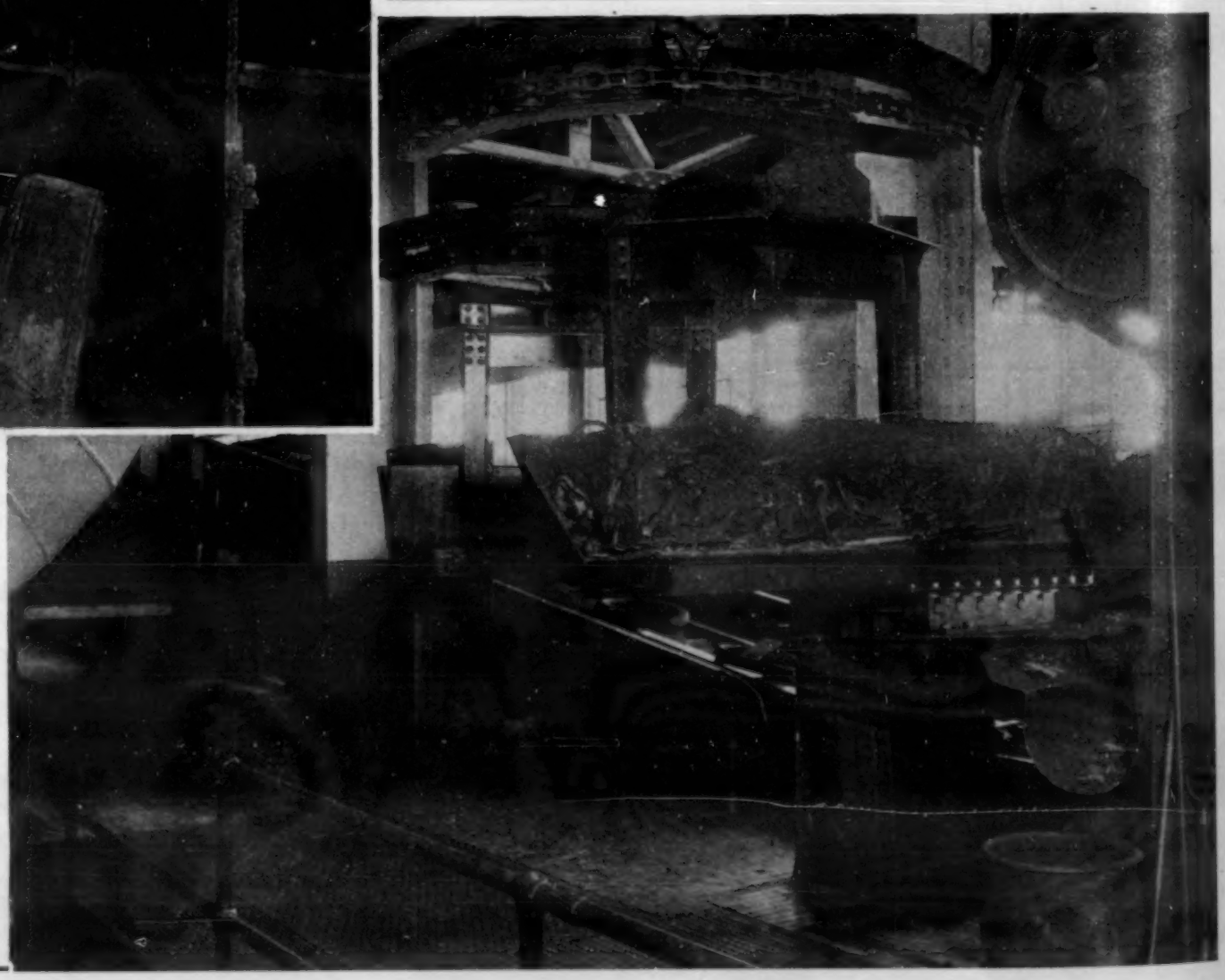
Nickel, copper, tin, chromium, and manganese determinations were made on the composite samples of the different plants, and vanadium, molybdenum, zinc, lead, and arsenic on a general composite of all samples submitted over a 6-month period. Manganese was determined, as it is a residual metal, although it is purposely added to the charge, principally in the pig iron, so as to



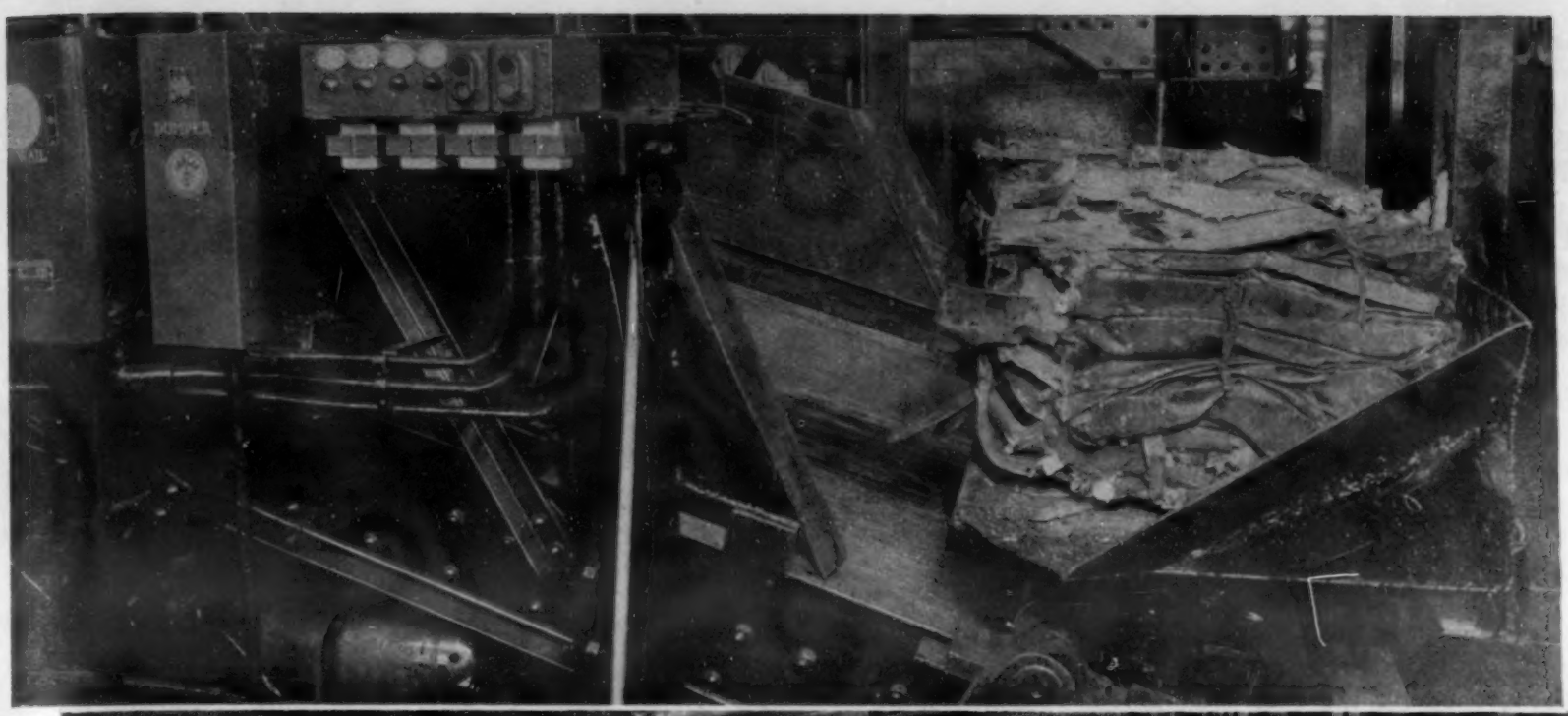


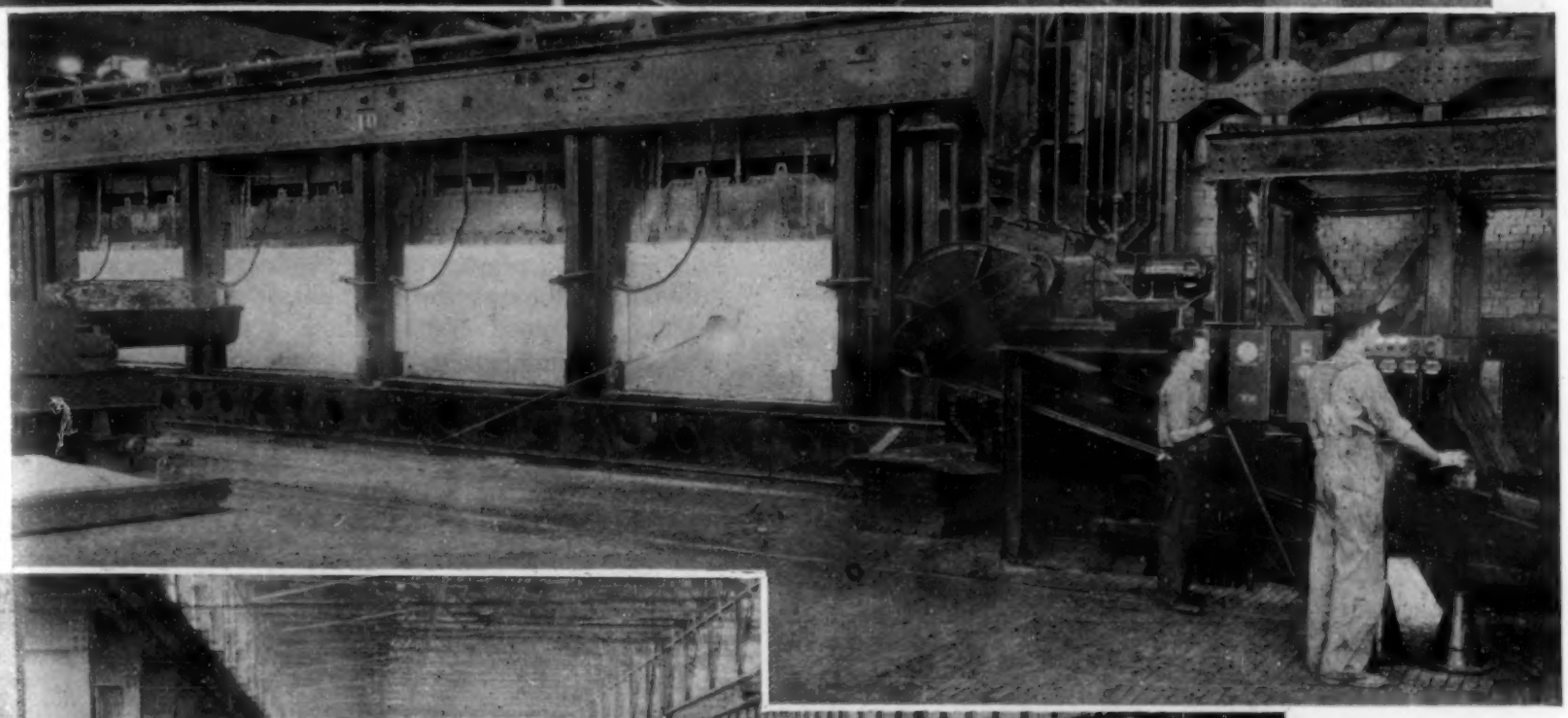
From "Graveyard" to Open-Hearth

Scrap Salvage Operations at Rouge Plant of Ford Motor Co.



Increasing the open-hearth melting facilities of the plant by 600 tons daily, the Ford salvage department's new $500,000 equipment includes a 1000-ton press which at one blow crushes a stripped car into a bale 6 ft. long, 30 in. wide and 18 in. deep. Top view shows nearly 5000 "retired" cars. Each is bought at a flat price of $20, is





stripped of glass, leather, batteries, etc., leaving an average of a ton of ferrous materials, and is rolled down to the giant baling press (middle view), after which the uniform bales are conveyed (bottom, left) and dumped from the conveyor to charging boxes (top, right). Next we see a charging box ready to be emptied into the new 400 ton furnace and last, a general view of the open hearth pit. Up to the time of writing the company has thus salvaged some 80,000 old cars.

finish the heat with from 0.11 to 0.25% residual manganese. Arsenic largely comes from the pig iron, but is included here for the sake of comparison.

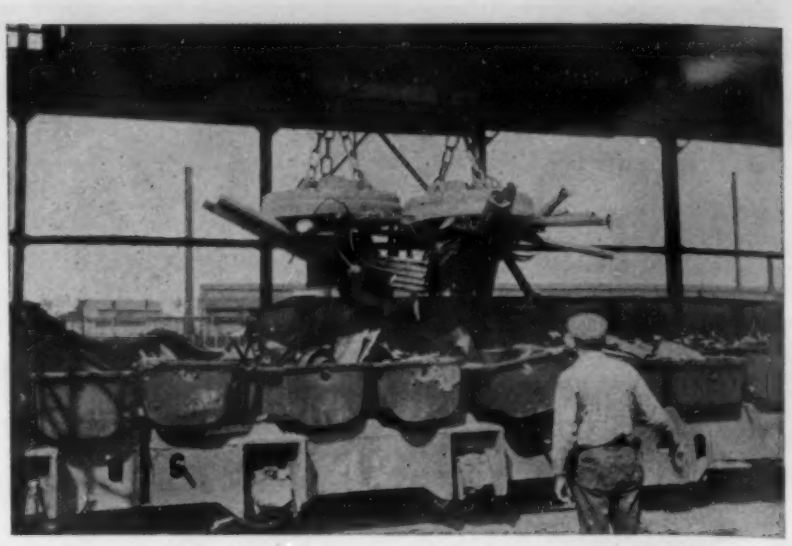
Tables I and II contain results of analyses for the past two 6-month periods and Table III of the general composite sample based on plant capacities.

The content of residual metals based on the tonnage capacity of 18 plants submitting samples was, for the period August 1931-January 1932, Mn 0.21, Cr 0.021, Ni 0.041, Cu 0.084, Sn 0.011, V <0.001, Mo <0.001, Zn <0.001, Pb <0.001, and As 0.001. Analyses of the last 5 elements in the small quantities present in steel are difficult and the results given for these elements at least show the maximum possible. Out of 21 analyses for vanadium made on individual plant composites, only 2 contained as high as 0.001% and most were under 0.0005%.

One cannot hope to learn much from a comparison of only two periods, especially with current interrupted operations. However, some interesting data have been collected showing the relationship between the residual metal content of the steel, the amount of automobile scrap used, and the ratio of scrap to pig iron in the furnace charge. This study, of course, would have to be continued over a period of years to establish definitely the exact changes in residual metals with changes in the amount and quality of scrap metal used.

A questionnaire was sent to each of the contributing companies, requesting (1) information as to whether more or less automobile scrap was used during the period August 1931 to January 1932 than normally; and (2) the ratio of scrap to pig iron used (a) August 1931 to January 1932, (b) March to July 1931, and (c) normally. Eleven of the 18 companies answered the questionnaire. On the basis of the answers submitted and the data in Table I, Table IV has been made. In Table IV, "up" indicates an increase in the percentage of the element for the period August 1931 to January 1932 over the period March to July 1931; "down" indicates a decrease; and "same" indicates no change. Of the 11 plants replying, 4 stated that more automobile scrap was used from August 1931 to January 1932 than normally and 7 reported that either no automobile scrap or a lesser amount than normally was being used. Three plants reported an increase in the ratio of scrap to pig iron for August 1931 to January 1932 over the period March to July 1931; 2 plants reported a decrease in the ratio; and 6 plants indicated the same ratio.

The data in Table IV show a marked correlation between automobile scrap used and changes in percentages of alloying elements present. For the 4 plants using more automobile scrap during the period, 68.7% of the analyses for the 4 elements, nickel, copper, tin, and chromium, increased, 18.8% decreased, and 12.5% remained the same; whereas for the 7 plants in which less or no automobile scrap was used, 28.6% increased, 67.8% decreased, and 3.6% remained the same.



Loading Scrap into Open Hearth Charging Boxes. (Courtesy Republic Steel Corporation.)

TABLE I. RESIDUAL METALS IN OPEN-HEARTH STEEL
March 1931-January 1932, Inclusive

	% Ni		% Cu		% Sn		% Mn		% Cr	
	1931	1931-32	1931	1931-32	1931	1931-32	1931	1931-32	1931	1931-32
Plant No.	Mar.-July	Aug.-Jan.	Mar.-July	Aug.-Jan.	Mar.-July	Aug.-Jan.	Mar.-July	Aug.-Jan.	Mar.-July	Aug.-Jan.
A	0.039	0.063	0.025	0.045	0.004	0.003	0.22	0.24	0.048	0.031
B	0.021	0.024	0.022	0.044	0.007	0.008	0.23	0.23	0.024	0.019
C	0.043	0.054	0.097	0.215	0.017	0.025	0.11	0.11	0.020	0.019
D	0.039	0.035	0.104	0.053	0.011	0.008	0.21	0.24	0.030	0.019
E	0.089	0.071	0.268	0.296	0.035	0.041	0.11	0.24	0.052	0.036
F	0.032	0.072	0.106	0.080	0.014	0.013	0.15	0.16	0.031	0.026
G	0.041	0.037	0.030	0.015	Nil	0.003	0.35	0.46	0.044	0.038
H	0.071	0.060	0.075	0.077	0.011	0.017	0.12	0.11	0.029	0.030
I	0.008	0.030	0.059	0.074	0.008	0.006	0.10	0.08	0.012	0.012
J	0.021	0.038	0.049	0.062	0.003	0.006	0.27	0.48	0.021	0.021
K	0.019	0.031	0.076	0.084	0.008	0.012	0.12	0.13	0.025	0.011
L	0.053	0.039	0.075	0.077	0.007	0.006	0.26	0.24	0.033	0.022
M	0.039	0.034	0.117	0.085	0.008	0.009	0.25	0.24	0.023	0.006
N	0.041	0.040	0.065	0.113	0.008	0.008	0.16	0.16	0.034	0.031
O	0.063	0.083	0.202	0.215	0.020	0.017	0.19	0.18	0.049	0.036
P	0.082	0.107	0.088	0.138	0.009	0.015	0.24	0.24	0.049	0.030
Q	0.057	0.050	0.122	0.114	0.021	0.022	0.25	0.23	0.049	0.046
R	0.063	0.044	0.040	0.032	0.005	0.004	0.26	0.31	0.021	0.021

TABLE II. AVERAGE RESULTS OF 18 PLANTS, PERCENT

	By Tonnage Capacity		By Plants	
Element	1931 Mar.-July	1931-32 Aug.-Jan.	1931 Mar.-July	1931-32 Aug.-Jan.
Manganese	0.20	0.21	0.20	0.23
Chromium	0.028	0.021	0.033	0.025
Nickel	0.037	0.041	0.046	0.051
Copper	0.077	0.084	0.090	0.101
Tin	0.010	0.011	0.011	0.012

TABLE III. CHEMICAL ANALYSIS OF GENERAL COMPOSITE SAMPLE COVERING THE PERIOD AUGUST 1931-JANUARY 1932

Element	Percent
Arsenic	0.001
Chromium	0.021
Lead	Less than 0.001
Molybdenum	Less than 0.001
Vanadium	Less than 0.001
Zinc	Less than 0.001

TABLE IV. CORRELATION OF ANSWERS TO QUESTIONNAIRE TO ANALYTICAL DATA COVERING THE PERIODS MARCH-JULY 1931 AND AUGUST 1931-JANUARY 1932

	Nickel			Copper			Tin			Chromium		
	Up	Down	Same	Up	Down	Same	Up	Down	Same	Up	Down	Same
All 18 plants	9	9	0	12	6	0	10	7	1	1	14	3
11 plants answering questionnaire	5	6	0	7	4	0	6	5	0	1	7	3
4 plants using more automobile scrap	3	1	0	4	0	0	3	1	0	1	1	2
7 plants using either less or no automobile scrap	2	5	0	3	4	0	3	4	0	0	6	1
3 plants in which ratio scrap:pig iron increased	2	1	0	3	0	0	3	0	0	1	1	1
2 plants in which ratio scrap:pig iron decreased	2	0	0	2	0	0	1	1	0	0	2	0
6 plants in which ratio scrap:pig iron remained constant	1	5	0	2	4	0	2	4	0	0	4	2

TABLE V. CORRELATION OF ANSWERS TO QUESTIONNAIRE TO ANALYTICAL DATA COVERING THE PERIODS MARCH-JULY 1931 AND AUGUST 1931-JANUARY 1932, WITH A TOLERANCE FOR ANALYTICAL ERRORS

	Nickel			Copper			Tin			Chromium		
	Up	Down	Same	Up	Down	Same	Up	Down	Same	Up	Down	Same
All 18 plants	8	5	5	10	6	2	7	2	9	0	11	7
11 plants answering questionnaire	4	4	3	5	4	2	4	1	6	0	6	5
4 plants using more automobile scrap	3	1	0	3	0	1	3	0	1	0	1	3
7 plants using either less or no automobile scrap	1	3	3	2	4	1	1	1	5	0	5	2
3 plants in which ratio scrap:pig iron increased	1	1	1	2	0	1	2	0	1	0	1	2
2 plants in which ratio scrap:pig iron decreased	2	0	0	2	0	0	1	0	1	0	2	0
6 plants in which ratio scrap:pig iron remained constant	1	3	2	1	4	1	1	1	4	0	3	3

Charging Scrap into Open Hearth. (Courtesy Republic Steel Corporation.)

The results are nearly as striking when considered on the basis of the ratio of total scrap to pig iron used. For the 3 plants in which the ratio increased, 75.0% of the analyses for the 4 elements increased, 16.7% decreased, and 8.3% remained the same. For the 2 plants in which the ratio decreased, 62.5% of the analyses increased and 37.5% decreased. For the 6 plants in which the ratio remained constant, 20.8% of the analyses increased, 70.8% decreased, and 8.3% remained constant. The apparent contradiction to the usual finding in the case of the 2 plants in which the ratio of scrap to pig iron decreased is partly explained by the fact that in one of the plants, although the amount of total scrap used decreased, the amount of automobile scrap increased.

Table V is given because some may object to the fact that, since a small change in composition is within the limits of analytical error, some of the analyses in Table IV indicated as increasing or decreasing should have been reported as remaining constant. In Table V, any change of $\pm 0.005\%$ for nickel or copper, $\pm 0.004\%$ for chromium, and $\pm 0.002\%$ for tin is taken as indicating no change. The same general picture as that in Table IV is shown in Table V. The only marked difference is that more of the analyses for tin appear as unchanged.

Methods of Chemical Analysis

The following short résumé of the methods of analyses used for nickel, copper, tin, manganese, and chromium is given. Analytical determinations of small amounts of residual metals in steel are very difficult. Accurate determinations can be made only by using slow detailed methods. Umpire rather than routine methods are required.

Nickel. Samples are dissolved in hydrochloric acid, the iron oxidized with nitric acid, citric acid added, and the nickel precipitated in slightly ammoniacal solution with dimethyl glyoxime. Frequently all of the nickel is not precipitated; so, after filtering off the $NiC_8H_{14}O_4N_4$, the filtrate is made slightly acid and then slightly ammoniacal to precipitate any remaining nickel. A third precipitation is sometimes necessary.

Copper. Samples are dissolved in dilute sulphuric acid. Any insoluble residue is filtered off, treated with aqua regia, and then taken to fumes with sulphuric acid. The soluble material is brought into solution and added to the original filtrate. Copper is precipitated with sodium thiosulphate and determined by the potassium iodide method.

Tin. Samples are dissolved in dilute nitric acid, the tin precipitated as sulphide with hydrogen sulphide and the tin sulphide converted to sulphate. To the tin sulphate, ferric chloride is added and the tin and iron are precipitated with ammonium hydroxide. The precipitate is dissolved in hydrochloric acid, the tin reduced with lead in a carbon dioxide atmosphere, and determined by titration with iodine. The method is the same as outlined in Bureau of Standards Research Paper No. 415.

Manganese. The bismuthate method is employed, as it gives more satisfactory results than the persulphate method.

Chromium. Samples are dissolved in dilute sulphuric acid. Any insoluble matter is treated as described in the method for copper. Chromium is precipitated by adding an 8% solution of sodium bicarbonate until a permanent precipitate appears and then about 5 cc. in excess. The precipitate is filtered, ignited, and fused with sodium peroxide in an iron crucible. The mass is leached with water and filtered, and the chromium determined colorimetrically in the filtrate.

Accuracy of Analytical Determinations

The detection of any trend of increase or decrease in the amount of the various residual metals entering steel through scrap depends on the accuracy of analytical methods involved. Unfortunately, analytical methods are subject to inherent errors and when only small amounts of the metals are present the degree of accuracy may be low. The U. S. Bureau of Standards furnishes various standard steel samples and supplies with each a certificate of analysis. In Table VI are tabulated data for four such samples.

The Bureau of Standards sends samples to various analytical laboratories that are believed qualified to analyze samples for the elements desired and the results are indicated on the certificate. The certificates show good agreement between the various analysts for manganese, but rather poor agreement for the other three elements, especially for nickel and chromium.

Data for tin are not available. Variations between the results of different analysts for nickel are as great as tenfold. While the percentages of the various elements are not the same in the Bureau of Standards samples as in those investigated by us, the analyses, nevertheless, show the variations obtained by different analysts on the same samples. It would appear that detection of small changes in the amount of residual metals is difficult and that, to make the study mean anything, it must be continued over a long period and analyses should be made under identical conditions.

The Bureau of Standards certificates present further interesting information other than that given in Table VI. Samples 8d and 9c are Bessemer steel. Sample 8d contains 0.003% vanadium, 0.003% molybdenum, and 0.007% arsenic. Sample 9c contains 0.006% vanadium, 0.003% molybdenum, and 0.009% arsenic. Both samples contain 0.007% chromium.

It is hoped to continue the study of residual metals in open-hearth steel over a long enough period to establish definitely the trend and to determine the rate at which the concentrations of the various residual elements are changing.

TABLE VI

	Nickel				Copper				Manganese				Chromium			
Analyst	8d[b]	9c[c]	12d[d]	33b[e]	8d	9c	12d	33b	8d	9c	12d	33b	8d	9c	12d	33b
1[a]	0.004	0.002	0.002	3.48	0.011	0.020	0.016	0.105	0.486	0.663	0.342	0.705	0.006	0.007	0.015	0.025
2	..	0.005	0.006	3.48	0.012	0.020	0.018	0.108	0.487	0.660	..	..	..	0.004	0.011	0.038
3	..	..	..	3.46	..	0.025	0.015	0.110	..	0.664	0.344	..	..	0.007	0.020	..
4	..	..	0.01	3.50	0.014	0.02	0.010	0.120	0.485	0.67	0.349	0.694	0.10	..	0.008	<0.01
5	0.005	..	0.001	3.49	0.017	0.017	0.018	0.12	..	0.669	0.342	0.699	0.006	..	0.018	0.028
6	..	..	..	3.49	0.013	..	0.015	0.098	0.482	..	0.345	0.700	..	..	..	..
7	..	..	0.006	3.51	0.011	0.017	0.012	0.12	0.474	0.668	0.350	0.694	..	..	0.015	..
8	..	..	..	3.48	0.012	..	..	0.126	..	..	0.341	0.692	..	..	..	..
9	<0.002	..	0.01	3.47	..	0.016	0.01	..	0.48	0.669	0.340	..	<0.01	0.008	<0.01	0.018
10	0.005	0.003	0.007	3.50	..	0.018	0.019	0.11	0.481	0.668	0.333	0.70	0.005	0.008	0.013	0.040
11	..	..	0.01	..	..	0.023	0.019	..	..	0.67	..	..	..	..	0.018	..
Average	0.004	0.003	0.007	3.48	0.013	0.020	0.015	0.114	0.482	0.667	0.343	0.698	0.007	0.007	0.015	0.029

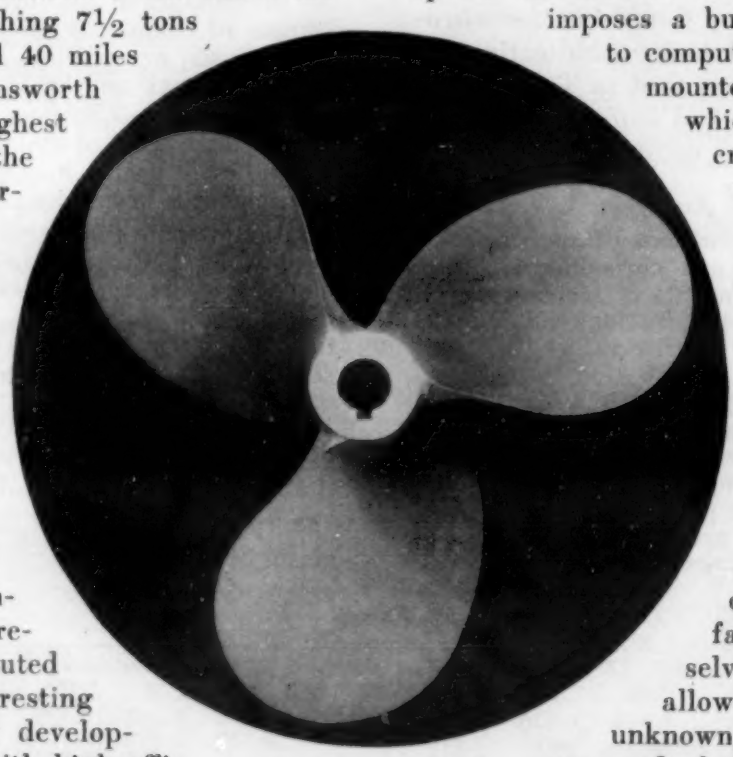
[a]Number of analyst refers to each sample only. Different analysts for different samples, but for each sample the same analyst for various elements.
[b]0.1 C. Bessemer steel.
[c]0.2 C. Bessemer steel.
[d]0.4 C. Basic open-hearth steel.
[e]0.37 C. Nickel steel.

Miss America X doing 124.91 M. P. H. on St. Clair River, Algonac, Mich., September 20, 1932.

Design and Construction of

By E. K.

IN A DRIZZLING rain early on the morning of September 20th, Gar Wood in his latest speed boat creation, Miss America X, regained for the United States the record of highest speed ever attained on water. Electrically timed on a mile course at Algonac on the St. Clair River, he averaged 124.91 miles per hour, bettering by more than 5 miles per hour the English record established in July on Loch Lomond, Scotland. Such speed even with automobiles is well out of the ordinary, but with a boat weighing 7½ tons which a few weeks before stood 40 miles of a pounding sea in the Harmsworth Race, becomes a feat of the highest order. Early in the study of the propellor problem for Miss America, it was recognized that the conventional type wheel was entirely unsuitable for such propulsion requirements. High frequency shock, heavy thrust, and high propeller speed combined to give blade stresses dangerously close to the limit of sand cast materials. Thicknesses sufficient to carry thrust loads with a fair margin of safety, developed centrifugal stresses with bending resultants many times the computed thrust. The problem was an interesting one and eventually led to the development of a new type propeller with high efficiency, great smoothness in operation, and reduced blade thicknesses.



With a consumption of 5 gallons per mile, Miss America's four 12 cylinder engines deliver 6400 horse power to her propellers. Each propeller must transmit 3200 horse power at an r.p.m. of 7700, without permanent bending and without appreciable flexure. Bending even to very slight extent at the root of a blade is so amplified at the tip that the result is loss of pitch uniformity, lower r.p.m. and loss of efficiency. Flexure under load results in vibration which again affects power and efficiency, and exerts a tremendous influence on the ability of the driver to withstand the strain of terrific speed. In addition there is another factor; one which imposes a burden difficult, if not impossible, to compute. Miss America's propellers are mounted behind a shaft hanger or strut which parts the water into 2 streams, creating a rarefied channel through which each blade must pass. A shock load of varying intensity is thus set up which can have a maximum frequency of over 23,000 per minute. The dimensions of this channel and the density of the water therein are matters of conjecture, but it is safe to assume that a large percentage of load on each blade is momentarily released and applied once each revolution. These load factors known to exist are of themselves quite formidable, but adequate allowance must also be made for the unknown, such as the encounter of submerged obstructions and shocks incident to rough water. Such submerged obstructions are a constant hazard, and a broken blade through lack of toughness may cause a serious accident. Harmsworth races have been frequently run over very choppy seas with propellers at times thrown clear of the water. A bent blade under the impact of resubmergence might easily cost a race.

The sketch here shown of a conventional type blade is a cross section similar to the original propeller in-

*Chief Metallurgist, Federal Mogul Corporation, Detroit, Michigan.

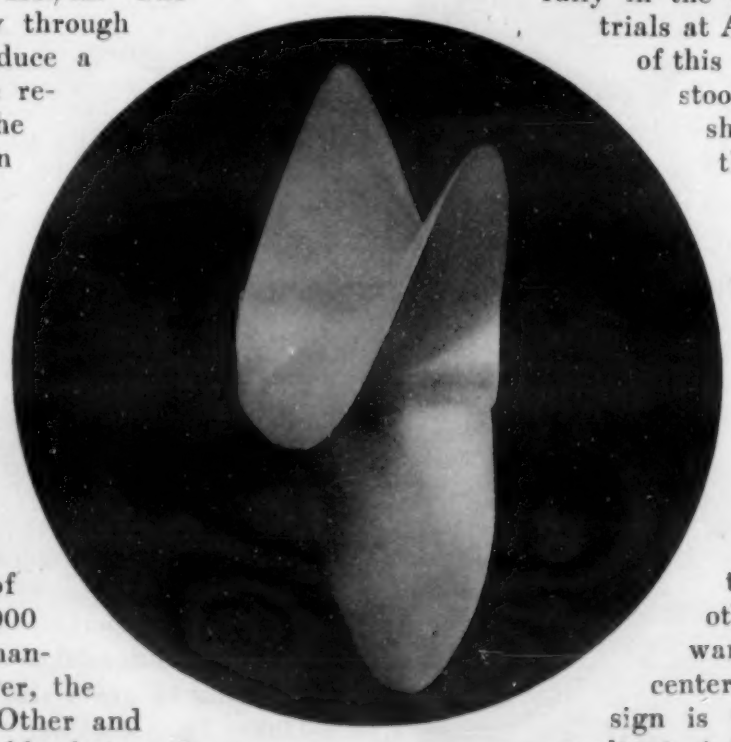
Gar Wood (left) and Orlin Johnson at completion of "Record Run."

Propellers for Miss America X

ARBY*

tended for Miss America. The working surface or face of each blade is a portion of a true square thread, coincident at any vertical section with an extended radius. The thrust was calculated as being active for a distance of 3 inches only from the tip of the blade, and the root thickness to withstand this thrust was proportioned for an extreme fiber stress of 5000 lbs./in.^{2} The centrifugal force acting radially through the center of mass would produce a stress of 8000 lbs./in.^{2} and the resultant bending stress, due to the center of mass seeking to align itself with a radius through the intersection of the neutral axis and the hub circumference, would approximate 15000 lbs./in.^{2} Although this analysis is not absolutely correct it will serve as an illustration, and we have—

Thrust Load	5000 lbs./in.^{2}
Centrifugal Load	8000 lbs./in.^{2}
Resultant Bending	15000 lbs./in.^{2}
Total	28000 lbs./in.^{2}



With the proportional limit of cast aluminum bronze at 30,000 lbs. at the top and that of manganese bronze considerably lower, the design was obviously unsafe. Other and stronger materials were available but each had its peculiar difficulties from the angle of manufacture. Forgings were out of the question as it was necessary that a number of sizes and different pitches be tried to assure the best combination for highest speed. This could not easily be done in the short time available by any method other than sand casting. Several copper base alloys which in sand cast form can have their properties greatly improved by precipitation hardening, could have been used. These, however, are more or less in the experimental stage and presented the difficulty of warpage incident to high temperature heat treatment.

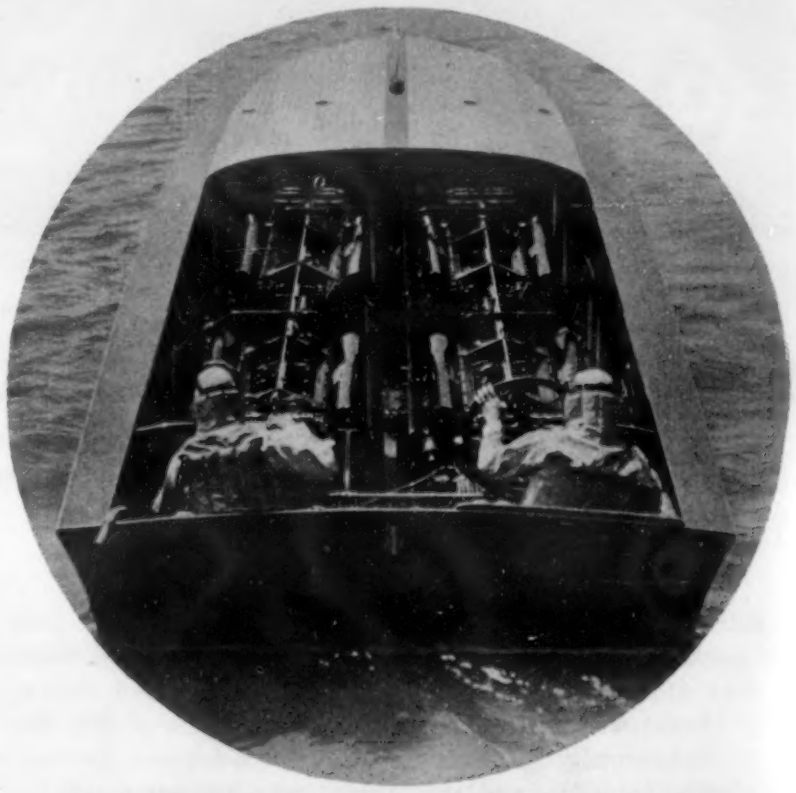
Warped blades even of normal section are, because of surface curvature, difficult to return to accurate pitch; and with the increased thickness of the blades for Miss America, straightening would have been a serious undertaking. Change of design seemed the logical way out, and it was the attack of the problem from this angle that resulted in the "Equipoise Blade" used so successfully in the Harmsworth Race and the time trials at Algonac. The principle and value of this new design can be readily understood by comparing the 2 sketches as shown. In the "Equipoise Blade" the working surface or blade face is over its full extent a portion of a "V" thread with the back or opposite surface so located that the neutral axis of the middle section coincides with a radius drawn through its center of mass. By curving the back each way from the middle section to meet the working face at the entering or trailing edges of the blade the neutral axis of the various other sections are inclined backward from a radius through their centers of mass. The result of this design is the elimination of the bending resultant at the middle section due to centrifugal force, and the setting up of such bending resultants in the various other sections opposed to the direction of thrust. In other words, the total load under identical power and speed was more than cut in half.

In order to prove the correctness of the principle, a 12 inch diameter, 13 inch pitch propeller was hastily made and tried on a high speed runabout which in the past had given much trouble in blade distortion and vibration. The results were highly satisfactory and blade

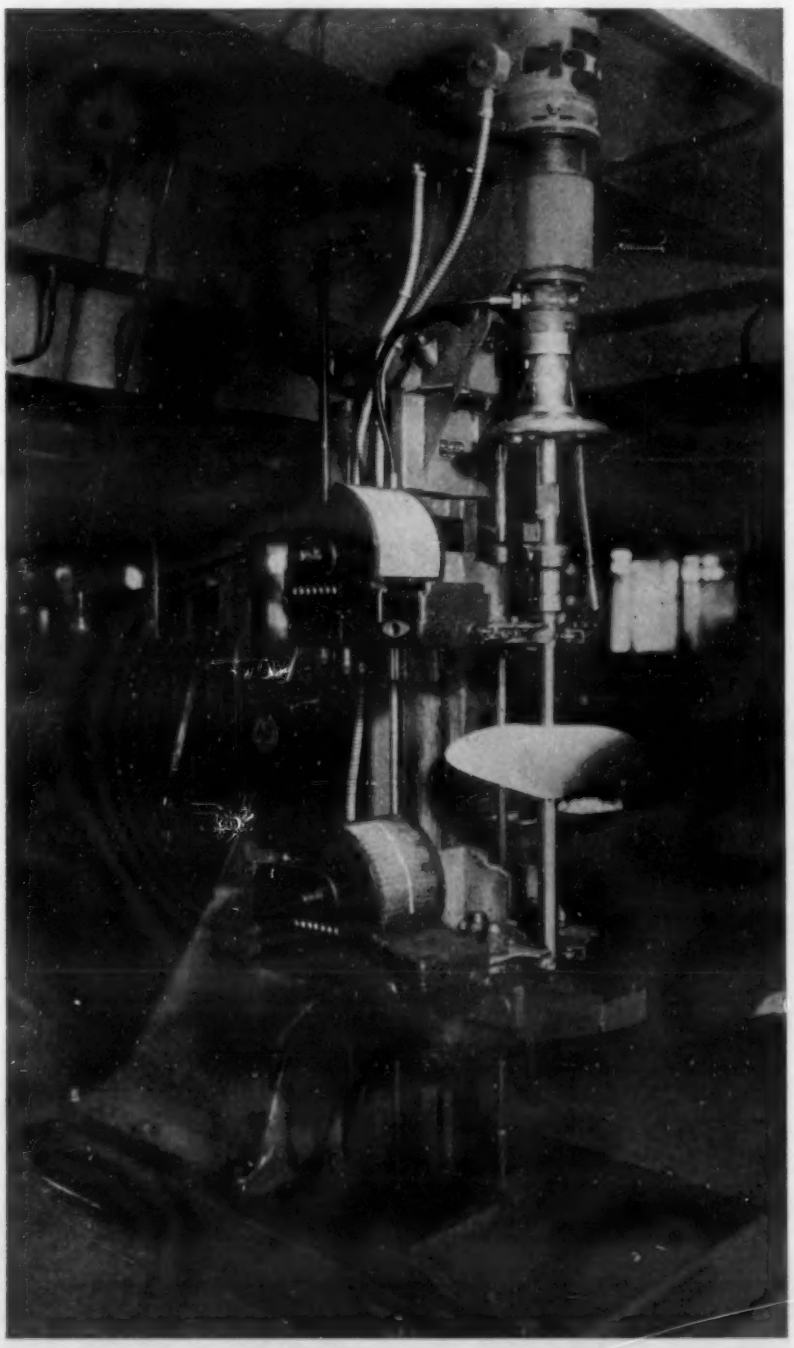
whip with its accompanying vibration seemed completely corrected. A design was then drawn for Miss America and without modification other than slight changes in diameter and pitch was the one ultimately adopted.

In this design the root thickness of the blade was 1¼ inch at the middle section and proportionately decreased toward the entering and trailing edges. At the middle section the total of the computed stresses was approximately 12,000 lbs./in.^{2} and at the various other sections much less than this figure. The hub length in this design as in the former or conventional type was 6 inches with an outside diameter of 2⅝ inches. It was bored to fit a 1⅝ inch shaft with a standard taper of ¾″ to 1 ft. As the thrust on each of the propeller shafts was about 9000 lbs., the hubs of the propellers were tested by forcing a taper plug into them under 18000 lb. load. This gave a total bursting pressure on the surface of the bore of about 25,000 lbs./in.^{2} and provided a rough means of judging the soundness of the casting.

Propellers of both types were ready for trial and under as nearly identical running conditions as possible were given a high speed test. The conventional wheel showed serious distortion at the end of the test, and throughout the run set up a very objectionable vibration. The new design wheels not only showed unusual efficiency but were without distortion and were practically free of vibration. This difference in performance with respect to vibration was in no way due to original balance of the propellers as both types were dynamically balanced on a Summers-Van Degrift machine at the General Motors Research Laboratory. With respect to performance under prolonged high speed and severe shock conditions it is interesting here to note that the same pair of propellers which had seen over 100 miles of high speed service in trial runs were used on Miss America in both heats of the Harmsworth race. In spite of the fact that a new pair of wheels were in the beginning provided for each heat, the blades on these mentioned were so free of deformation that Mr. Wood insisted upon using them.



Wood and Johnson ready to start Record Run—View showing Arrangement of 4 Packard 12-cyl. Engines.



Dynamic Balancing of Miss America X Propellers.

The metal used in casting the "Equipoise" propellers was an aluminum bronze of the 88-9-3 composition, slightly modified by additions of manganese and zinc. The physical properties of this alloy as cast in moderate section are, roughly—

Tensile Strength	80,000 lbs./in.^{2}
Proportional Limit	30,000 lbs./in.^{2}
Elongation	30%
Hardness	72 Rockwell B.

Cast in Miss America's propellers there is a noticeable decrease in grain size from hub to blade tip. This, however, is not accompanied by any important change in physical properties. The proportional limit at the hub is slightly under 30,000 while that of a ¼ inch test bar comparing in grain size to the blade tip is slightly over 30,000. The Rockwell hardness at the hub is 71 and averages 73 at the blade tip. Strength and elongation do not vary.

Manganese and zinc are introduced in amounts less than 1%. The combination of the two adds fluidity and greatly improves the proportional limit. Increasing the zinc content materially increases hardness, but elongation falls off very rapidly and tensile strength is lowered. The microstructure is not affected by the additions used, but if the amounts be increased to any great ex-

tent the area of the alpha constituent is reduced with an approach toward brittleness.

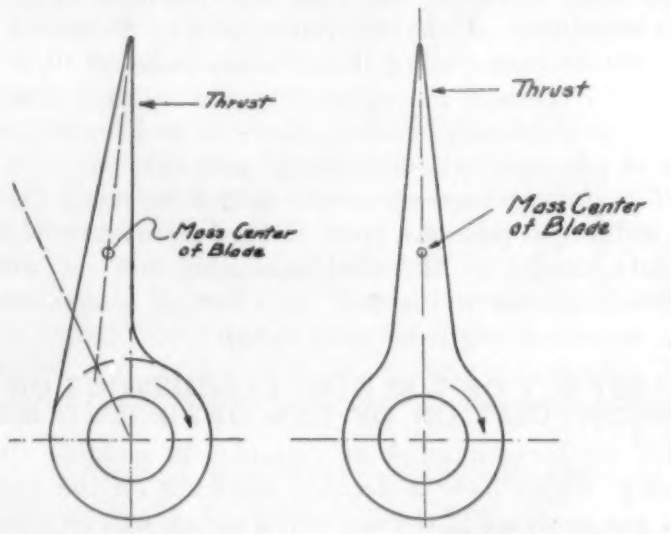
The usual precautions in melting and pouring aluminum bronze were observed in handling this alloy. It was first compounded in 500 lb. lots and poured into ingots for analysis purposes. The castings were poured from 100 lb. heats melted in a coke fired crucible furnace under an exceptionally heavy covering of charcoal. About 10 minutes before removing the crucible from the fire the melt was deoxidized with ½% of calcium copper, and at the time of skimming and just before pouring was fluxed with a few ounces of sodium chloride. Pouring was started at a temperature of 2050°F. and the metal flowed into the mold as slowly as consistent with complete filling of the blade sections. Horn gates and risers were used as shown by photograph.

Different from other products, propellers must be cast to almost finished dimensions. Machining with exception of hub bore and faces is in reality confined to light grinding and buffing. With blade sections as heavy as in Miss America's propellers, castings must be extremely accurate as correction of inequalities in pitch and blade surface contour cannot be made by hammering to shape. Any attempt of this nature, even if successful, will result in blade movement after a few days in storage unless the straightening operation be followed by extremely careful annealing.

As static balancing during the finish grinding is an excellent index of the soundness of castings, particular

DATA ON MISS AMERICA X

Length of Hull	38′ 9″	Propellers (2)	17″ diam.
Beam	10′ 6″	Propeller Pitch	22″
Fuel Capacity	300 gal.	Propeller Hub Length	6″
Displacement at rest	7.5 tons	Propeller Hub Diameter	2.625″
Engines (4 12-cyl. V type)	6400 H.P. max.	Propeller Blade Area (effective)	72 in.²
Engine Speed	2600 r.p.m. max.	Driving Load on Each Propeller	3200 H.P. max.
Fuel Consumption per mile	5 gal. max.	Thrust on Propeller Hub	9000 lbs.
Drive Shafts (2)	1.625″ diam.		
Drive Shaft Speed	7700 r.p.m. max.		

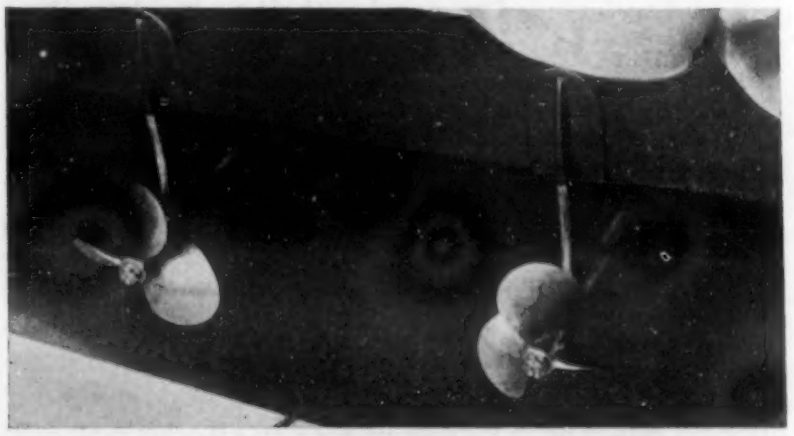


Cross-section of Conventional Propeller.

Cross-section of "Equipoise" Propeller.

Rough Casting showing Gate and Riser. Miss America X Propeller.

attention was paid this operation. One casting requiring very heavy grinding to balance it, was rejected, and subsequent examination revealed serious shrinkage in 2 blades. Little trouble was experienced in dynamic balancing, largely because of the attention paid to static balance. In daily production, slow and moderate speed propellers are not dynamically balanced but with the 7700 r.p.m. requirement such an operation immediately preceding the polish was imperative.



"Equipoise" Propellers in place on Miss America X.

Balanced and polished, the buffing or "coloring" operation finishes the story and Miss America's propellers are ready for use. Their mirror like surfaces, although adding greatly to their appearance, are for the purpose of reducing skin friction and give the last mile per hour so important in a race.

Gar Wood's achievements in the Harmsworth Race and in his record breaking run at Algonac, should go into history as the result of profound thought and untiring attention to every detail in the assembly of a remarkable craft. Propellers are but parts of a whole, the failure of any member of which might spell defeat or disaster. From bow to stern Miss America X was a perfectly timed unit, but even as such, the picture is not complete, for we must add to it the skill and fearlessness of a "Wood" and a "Johnson" to stand the physical and nervous strain of 125 miles an hour on water.

Metallurgy of Some Variables in Arc Welding

By F. R. HENSEL† and E. I. LARSEN†

INTRODUCTION

UP TO THE present time the technique of welding has been most emphasized. The art is finding new applications in highly stressed machine parts and structures requiring the best physical properties. Here the metallurgical characteristics of the deposited metal become of outstanding importance, although this is not yet fully realized in engineering and welding circles. In previous publications[1] the authors have discussed a number of phases of the metallurgy of welds.

The present paper presents data concerning the effect of welding conditions upon the nature of the deposited metal, results of the McQuaid-Ehn test on different types of fusion welds and the effect of temperature on the impact strength of weld metal.

A. EFFECT OF WELDING CONDITIONS ON THE COMPOSITION OF THE DEPOSITED METAL

Of the large number of variables in welding the following, which have a decided influence on the chemical and gas analyses of the deposited metal, will be discussed here:

1. Arc Length (bare wire).
2. Shielding (bare wire).
3. A.C. Welding Compared with D.C. Welding (bare wire).*
4. Electrode Coatings.
5. Atmosphere in the Vicinity of the Iron Arc.

1. Arc Length (bare wire)

In bare wire hand welding the arc voltage, which is a function of the arc length, is one of the major variables influencing the deposited metal. It was studied by depositing weld metal with arc voltages varying from 13-30 volts, using 3/16″ diameter "bare" (sul-coat) electrode. The current was kept constant at 190 amps. The effect of arc voltage on the nitrogen content and the ultimate strength is plotted in Fig. 1. The nitrogen content increases with the arc voltage, while the ultimate strength shows a marked decrease. Tensile test specimens with .25″ test diameter and 1″ gage length were used. While at 13 volts the elongation in 1″ was 20% it dropped to 5-10% at 30 volts. The influence of the arc voltage on the chemical analysis is shown in Table I.

The trends of the manganese and silicon contents of the deposit are noteworthy. The manganese content has decreased from .25% at 13 volts to 0.05% at 30 volts and the silicon content is effected in a similar way. This indicates that with a longer arc the oxidation is increased and a higher FeO content in the metal must be expected.

2. Shielding (bare wire)

By depositing "bare" (sul-coat) wire in a hole 1″ diameter and 3″ deep ** drilled in a steel block it was found that the chemical and gas analyses were changed as shown in Table II.

The hole in the steel block was covered with asbestos to minimize access of air. Due to the shielding action the nitrogen content was decreased from .126% to approximately .04%, while very little manganese was lost as judged from the manganese content of the deposit. The bare electrode used for all tests contained approximately .15% C and .50% Mn.

3. A.C. Welding Compared with D.C. Welding (bare wire)

The properties of pads deposited under the conditions given in Table III were studied.

The chemical and the nitrogen analyses are recorded in Table IV.

The results are surprising. The carbon and manganese contents of both metallic and carbon a.c. arcs are much higher than those obtained with a d.c. arc. Especially

†Research Laboratories, Westinghouse Elec. & Mfg. Co.
*For these experiments a Westinghouse 200 amp. Flexarc A.C. Welder with high frequency arc control was used.

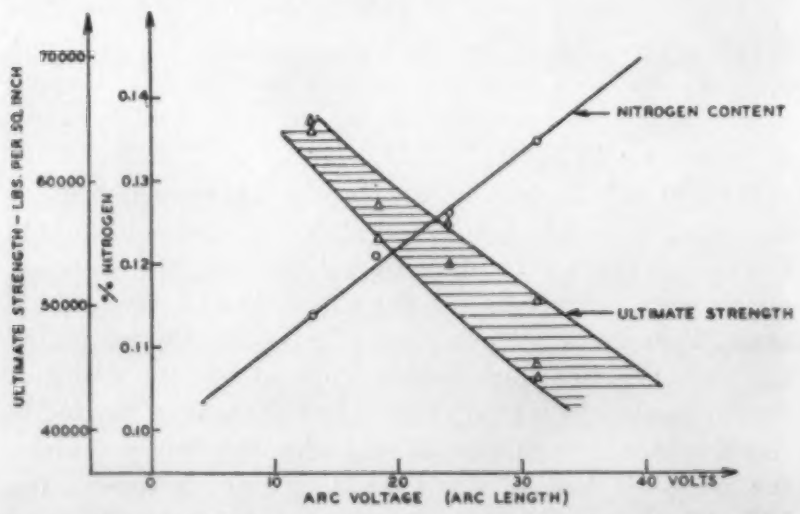


Fig. 1. Effect of Arc Voltage on Nitrogen Content and Ultimate Strength of Weld Metal.

TABLE I

Arc Voltage	C	Mn	P	S	Si	Nitrogen
13 volts	.02	.25	.010	.023	.014	.114
18 volts	.01	.11	.013	.025	.003	.121
24 volts	.03	.03	..010	.012	.006	.126
30 volts	.03	.05	.014	.020	.005	.135

TABLE II

	Nitrogen	C	Mn	P	S	Si
F.A. bare wire in open air	.126	.03	.03	.010	.012	.006
F.A. bare wire welded in 3″ deep hole in cold steel block	.038	.08	.42	.010	.020	.005

TABLE III

Pad No.	Electrode	Welding Technique
160	bare sul-coat F.A. 3/16″	220 amps. a.c.
162	bare sul-coat F.A. 5/32″	210 amps. a.c. carbon arc***
153	bare sul-coat F.A. 3/16″	180 amps. d.c. straight polarity
161	bare sul-coat F.A. 5/32″	180 amps. d.c. carbon arc***

TABLE IV

Mark	C%	Si%	Mn%	S%	P%	N_2
No. 160-220 Amps. AC	.10	.007	.20	.019	.012	.139
No. 153-180 Amps. DC straight polarity	.03	.006	.03	.012	.010	.126
No. 161-180 Amps. DC carbon arc	.01	.003	.06	.018	.009	.157
No. 162-210 Amps. AC carbon arc	.47	.012	.38	.021	.010	.056

**Although welding in a deep hole is not a commercial shielding method it was found to be a suitable means of studying self-shielding effects similar to those obtained under specially designed hoods. The prime object was to run a welding arc without allowing free access of air.

***The conventional carbon arc process was used in which the arc is drawn between electrode and work and not between 2 carbon electrodes as in the recently developed carbon arc torch.

marked is the difference between the d.c. and a.c. carbon arcs. Another factor of great interest is the nitrogen absorption, which is 3 times higher in the d.c. carbon arc than in the a.c. carbon arc. The differences between the a.c. and d.c. metallic arc deposits are much smaller. In general these variations must be attributed to welding techniques. It was found that a.c. carbon arc welding can be done satisfactorily only with a very short arc. This accounts for the decrease in nitrogen content since a short carbon arc will create a strongly reducing atmosphere. For a. c. metallic arcs also a shorter arc is held than for d.c. arcs. Here, however, the results are not consistent. In view of the larger amount of manganese present in the a.c. deposit we would expect a lower nitrogen content since high manganese and silicon contents are usually accompanied by a low nitrogen content. These elements seem to inhibit absorption of nitrogen and also increase its solubility in the ferrite.[2]

In this connection it might be pointed out that the carbon and manganese contents of the welding electrode also influence gas and chemical analyses of the deposits. This is illustrated in Table V. The gas absorption and the loss in manganese of the weld deposits are considerably smaller with Electrode B which has the higher C and Mn contents.

4. Coated Electrodes

There exist some difficulties in reporting test data of coated electrodes since the composition and the constitution of the fluxes are kept secret. It is hoped, however, that it will soon be possible to give a more complete account of the physical chemistry of this phase of arc welding.

Since nearly all coatings contain silicates as slag-forming ingredients as well as some type of organic matter for producing a desirable atmosphere, an appreciable shielding effect is obtained by welding in a groove. This was proved by depositing the coated wire W-98 (a) in form of a pad and (b) in a slot 2″ deep, ¾″ wide, formed by low carbon steel plates. The results are given in Table VI.

The difference in nitrogen content is very marked. The carbon content is raised from .07 to .12%—as a matter of fact the percentage of all chemical ingredients is higher.

The currents used for welding, with a given electrode, also noticeably affect the analysis of the deposited metal. This point is illustrated by the following results of a study of 2 flux-coated rods, namely, the "W-98" and "W-109," the latter containing the higher percentage of organic matter. 3/16″ wires were used with currents of 140, 180 and 220 amps. to build up pads of test material. The chemical and nitrogen analyses are collected in Table VII.

The results show that in the case of the W-98 the C, Mn and Si increased with the current density, while in the case of W-109 the same elements decreased with the current density. There is also a noticeable decrease in nitrogen in the W-98 with increasing amperage. On the other hand the physical test data of the W-109 showed the highest values of elongation at the lowest current value of 140 amps.

5. Atmosphere in the Vicinity of the Iron Arc

Analysis of samples of gas drawn from the neighborhood of the arc showed that the atmosphere around the bare wire arc at a distance of ½″ to ⅜″ had an oxygen content of approximately 14% by volume. The rest of the oxygen must have been used in oxidizing the chemical ingredients of the bare wire. When welding with a bare wire under a hood or in a deep groove the oxygen content of the atmosphere near the arc was found to be much lower and there was also a considerable increase in the CO_2, CH_4 and C_2H_6 contents. This fact is the explanation of the previously reported shielding effect. It was found that the composition of the gas taken during deposition of bare wire in a groove comes very close to that of the gas obtained near the arc with a heavily coated wire.

A more detailed investigation of the mechanism of gas absorption during welding is under way.

B. THE APPLICATION OF THE McQUAID-EHN[3] TEST TO DIFFERENT TYPES OF WELDS

Recently W. Zieler[4] reported some experiments in this direction. He came to the conclusion that a weld of good quality and uniformity will show a normal structure in the case carburizing test and he advocates the use of the McQuaid-Ehn test for judging the effect of different electrode coatings on the resulting deposit. On the other hand Duftschmid and Houdremont[5] point out that abnormality is a property of pure iron and pure iron-carbon alloys and that the use of the terms "normality" or "abnormality" of steel as a kind of quality factor is not justified. Their most important result is that abnormality is not caused by the presence of oxygen since all their samples contained .001% or less oxygen.

The first series of carburizing tests was made on all weld metal samples of a bare wire metallic arc weld, an oxyacetylene weld and an atomic hydrogen weld. Cross sections of these welds in the carburized zone are shown in Figs. 2 to 4 at a magnification of 75 diameters. The outer layer of these welds is shown at a magnification of 500 diameters in Figs. 5 to 7.

It is evident from the micrographs that the structure in all cases is exceedingly abnormal, the coagulation of massive cementite being most pronounced in the atomic hydrogen weld. The fact that in the eutectoid zone the abnormality is least pronounced, is easily explained by the large number of nuclei appearing at the eutectoid temperature which makes coagulation of large cementite particles difficult since the formation of massive cementite is favored by a small number of nuclei and a high velocity of crystallization.

From the chemical analysis it was evident that all 3 welds are nearly pure iron. For comparison, therefore, Armco iron, vacuum-melted iron and a pure iron melted under hydrogen were subjected to the McQuaid-Ehn test. All of these materials were very abnormal. This seems to indicate that abnormality in welds is not caused by

TABLE V

	C	Mn	P	S	Si	O_2 (Vacuum fusion)	N_2 (Vacuum fusion)	N_2 (Beiter's method)
Electrode A	.02	.03	.010	.021	.006	—	—	—
Deposit made with Electrode A (d.c.)	.027	.006	.016	.030	.004	.259	.127	.147
Electrode B	.285	.62	.010	.028	.003	—	—	—
Deposit made with Electrode B (d.c.)	.028	.27	.010	.035	.003	.183	.093	.128

TABLE VI

Mark	Nitrogen	C	Mn	Si	S	P
W-98 pad	.060	.07	.42	.19	.018	.012
W-98 2″ groove	.021	.12	.52	.215	.030	.016

TABLE VII

Mark	Amps.	C	Mn	P	S	Si	Nitrogen
W-98	140	.07	.40	.015	.033	.17	.072
W-98	180	.07	.46	.015	.032	.21	.066
W-98	220	.08	.48	.014	.031	.22	.059
W-109	140	.16	.44	.013	.024	.25	.065
W-109	180	.20	.41	.015	.023	.24	.061
W-109	220	.13	.37	.016	.022	.21	.065

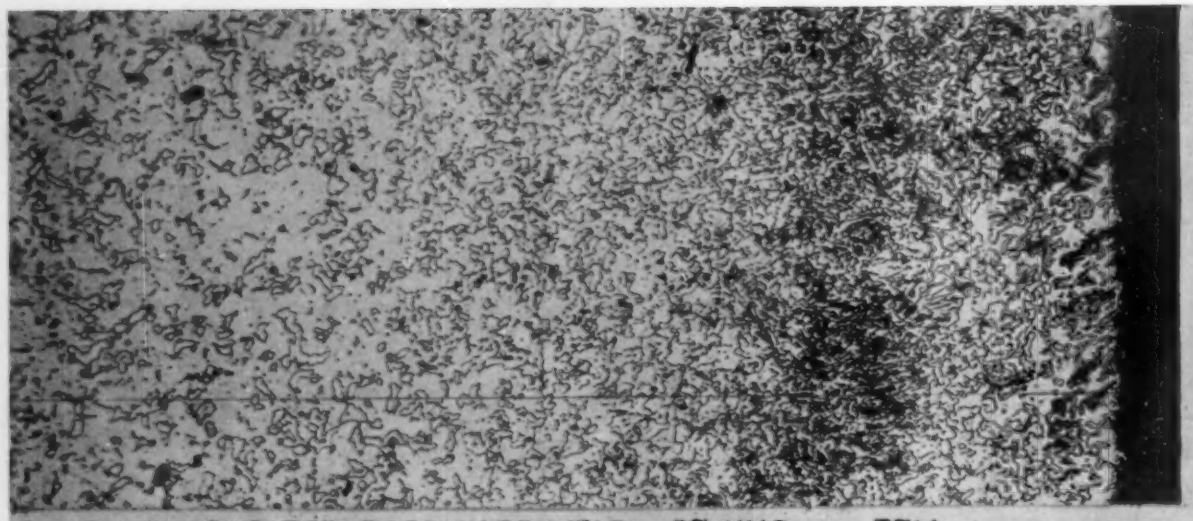


FIG. 2 CARBURIZED BARE WIRE WELD 5% HNO_3 75X

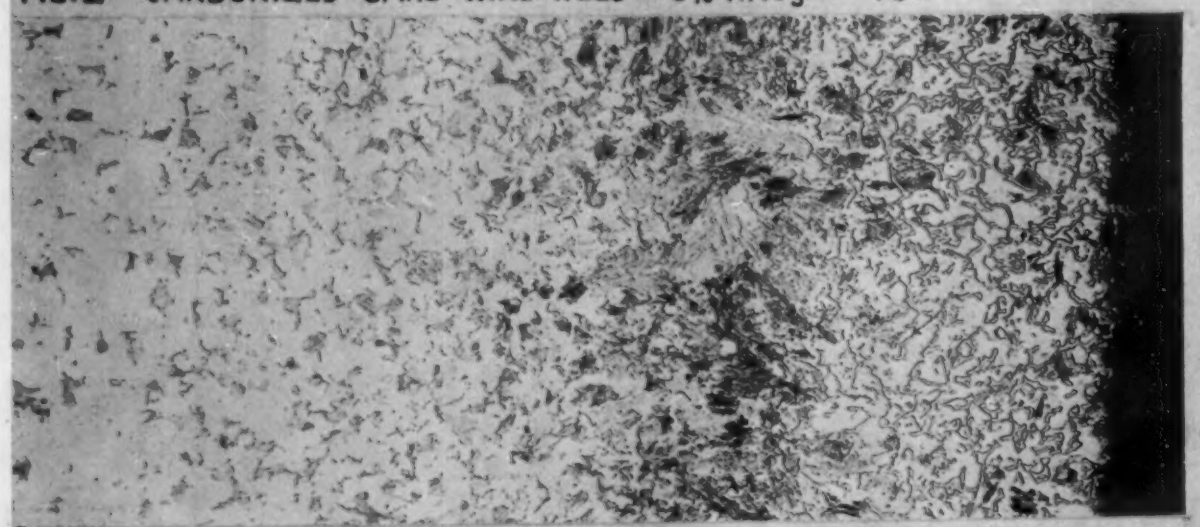


FIG. 3 CARBURIZED OXYACETYLENE WELD 5% HNO_3 75X

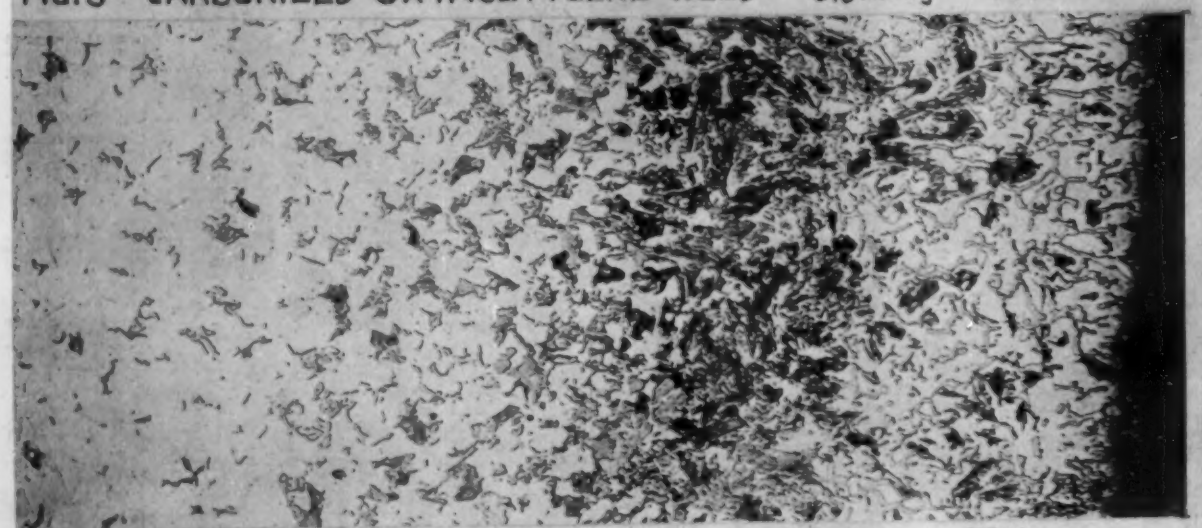


FIG. 4 CARBURIZED ATOMIC HYDROGEN WELD 5% HNO_3 75X

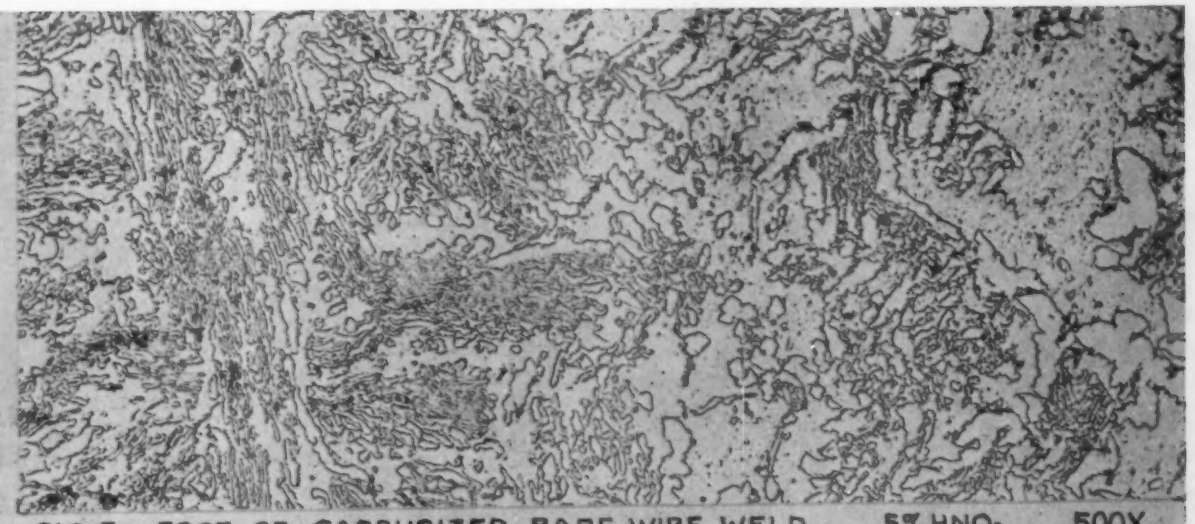


FIG. 5 EDGE OF CARBURIZED BARE WIRE WELD 5% HNO_3 500X

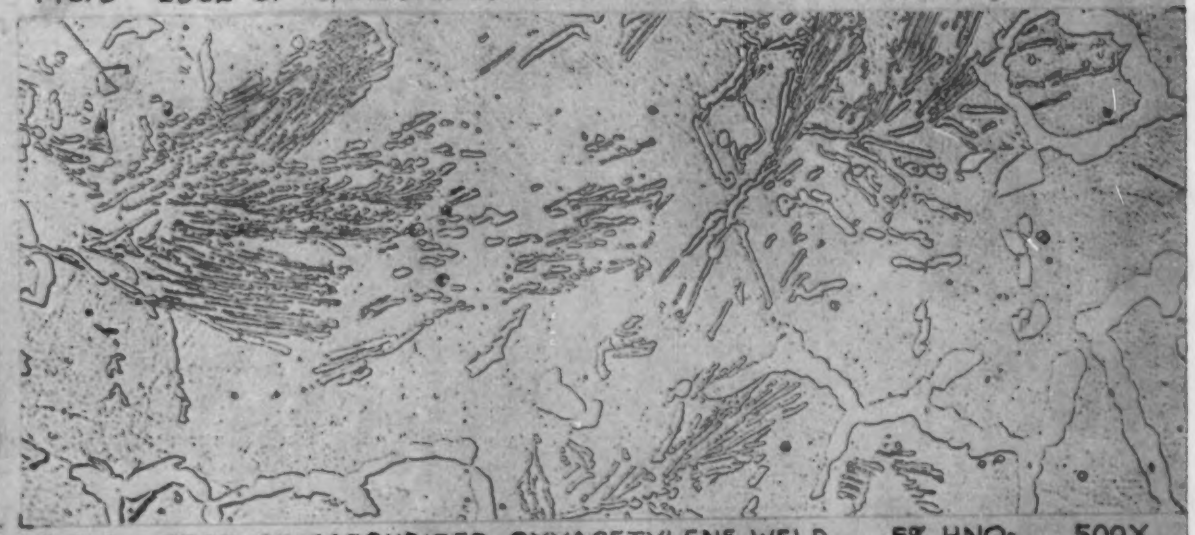


FIG. 6 EDGE OF CARBURIZED OXYACETYLENE WELD 5% HNO_3 500X

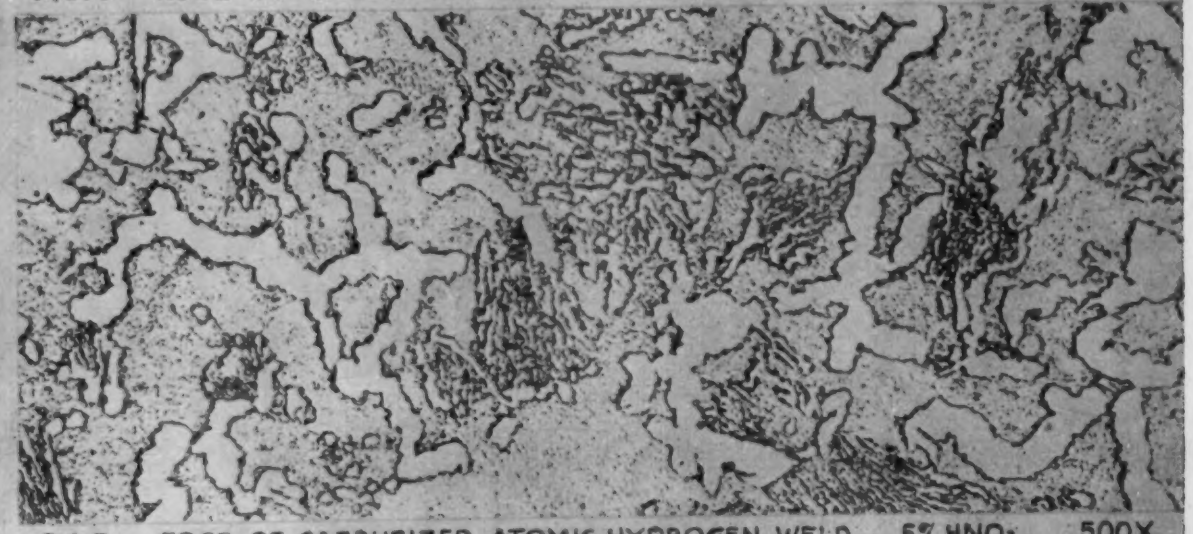


FIG. 7 EDGE OF CARBURIZED ATOMIC HYDROGEN WELD 5% HNO_3 500X

the presence of the high percentage of gases, but that it is a function of the chemical composition. The fact that practically all manganese and silicon are burned out during welding may be the reason for the abnormality.

For further tests 2 coated wire Vee welds and one bare wire Vee weld were investigated. The analyses of deposits with coated wire W-98 and coated wire "F" are collected in Table VIII.

TABLE VIII

Mark	%C	%Mn	%Si	%S	%P	O_2	N_2
Coated wire W-98	.070	.42	.19	.018	.012	.064 to .133	.03 to .06
Coated wire "F"	.10	.40	.12	.024	.020	...	.04 to .075

The bare wire was the same as used before. In Fig. 8 the appearance of the three Vee welds is shown after polishing and etching the outer surface of the carburized layer. The coated wire W-98 is completely normal. There is hardly any difference between parent metal and weld metal as seen from Fig. 9. The coated wire "F" has a normal zone in the center of the weld, while both ends show some abnormality. Fig. 10 shows the sharp demarcation line between the normal and abnormal parts of the weld. The bare wire weld again is extremely abnormal as evident from the macro- and micrographs in Figs. 8 and 11.

The chemical analysis of Table VIII suggests an explanation for the different behavior of the coated rods. The additional manganese and silicon contents in the welds made with the coated electrodes "W-98" and "F" are apparently responsible for the disappearance of the abnormality, although at the present time no definite explanation for this phenomenon can be given. In conclusion it can be said that the carburizing test is of value for testing welds insofar as inhomogeneities in the deposit are made easily visible by zones of normal and abnormal structure. It also gives some indication of the chemical analysis of the deposited metal.

C. THE EFFECT OF TEMPERATURE ON THE IMPACT STRENGTH OF WELDS

It is known that in mild steels after an aging treatment, consisting of cold deformation and aging either at room or elevated temperature, the decrease[6] in impact strength is shifted to higher temperatures.[7] This type of aging is favored particularly by "blue heat" temperatures and therefore becomes important in the construction and selection of boiler material. Welds are used now in boiler and pressure vessel construction and their susceptibility to this type of aging will be a vital factor affecting their suitability for this service. Temperature-impact curves of weld metal will also show their ability to withstand shocks at low temperatures. This is a very important factor for a large number of applications especially in the refrigeration and rail industry.

Two bare wire and two coated wire deposits were used for this study. Standard Charpy impact test specimens were machined from pads deposited with the coated electrode "F," the coated electrode "W-98," a bare welding wire "#93," containing .02% C, and a sul-coat finish bare wire "W-F-A" containing approximately .15% C and .50% Mn. The material was tested as received and as aged. The aging treatment consisted of a 10% cold deformation by cold rolling and a subsequent low temperature anneal at approximately 300°C. No attempt was made to find the most critical aging temperature in the blue brittle range of 200°-350°C. and considerable modifications in the impact strength of welds might therefore be expected with a change of annealing temperature.

Fig. 8. Carburization Tests of Various Welding Electrodes. Circles Show Location of Micrographs of Figs. 9-11.

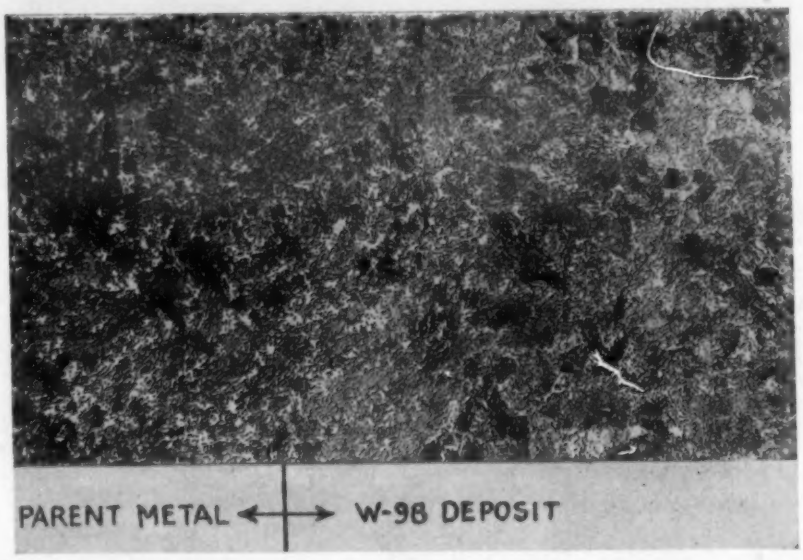


Fig. 9. Carburizing Test of Coated Wire W-98 V-Weld Deposit. Entire Weld Normal.

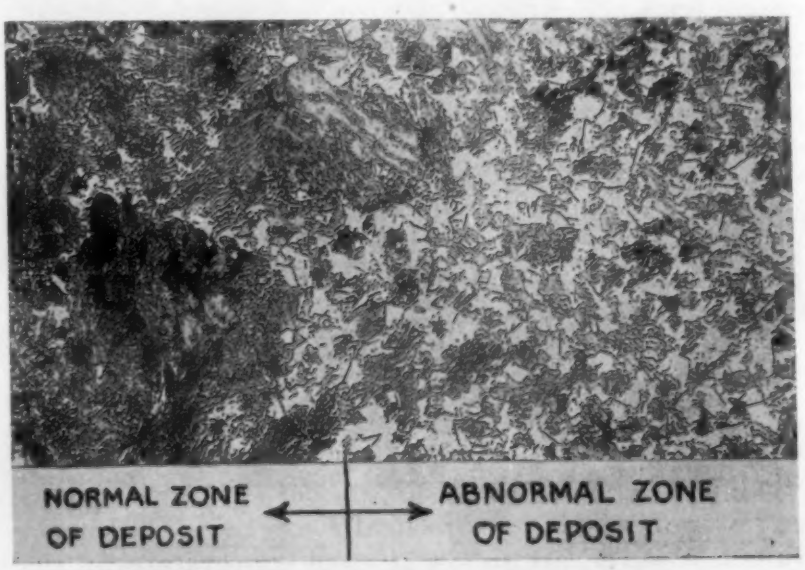


Fig. 10. Carburizing Test of Coated Wire "F" V-Weld Deposit. Weld Partly Normal and Partly Abnormal.

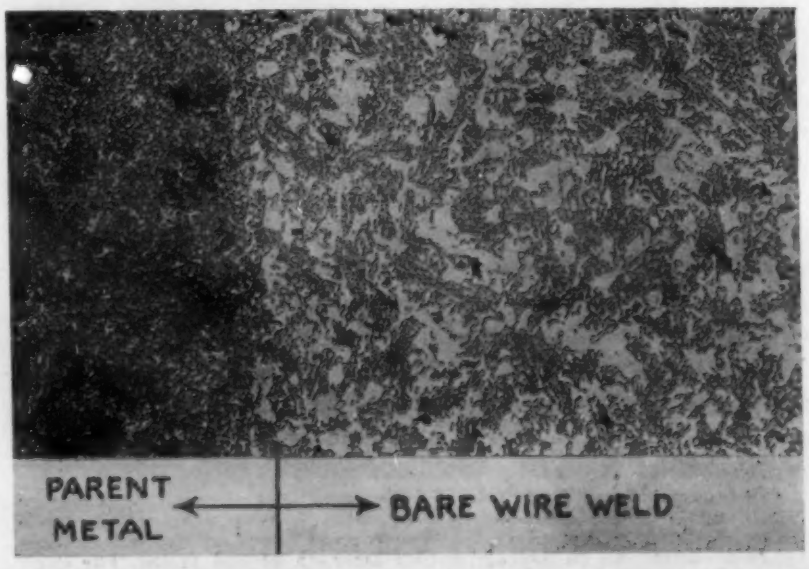


Fig. 11. Carburizing Test of a Bare Wire V-Weld. Entire Weld Abnormal

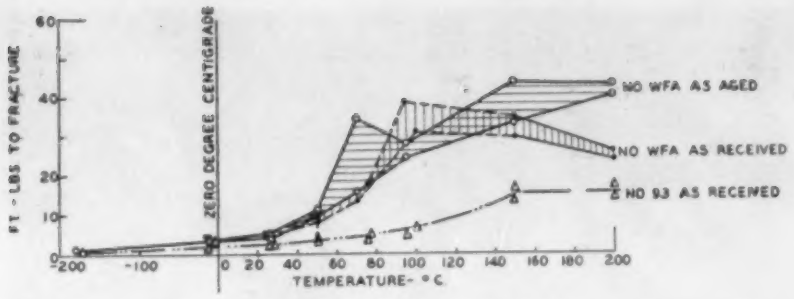


Fig. 12. The Effect of Temperature on the Impact Strength of all Weld Metal Deposited with a Bare Wire Electrode No. 93 and W-F-A.

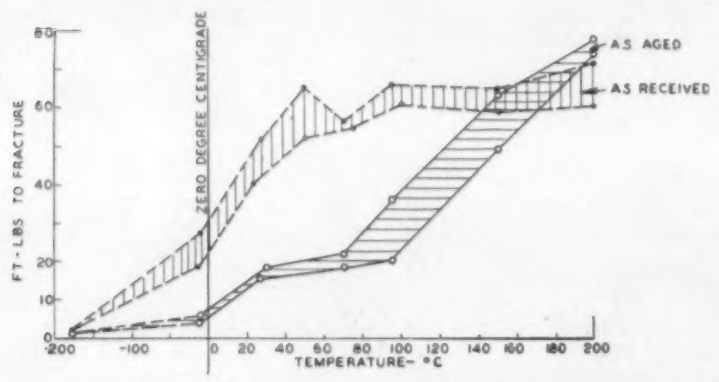


Fig. 13. The Effect of Temperature on the Impact Strength of all Weld Metal Deposited with Coated Electrode "W-98".

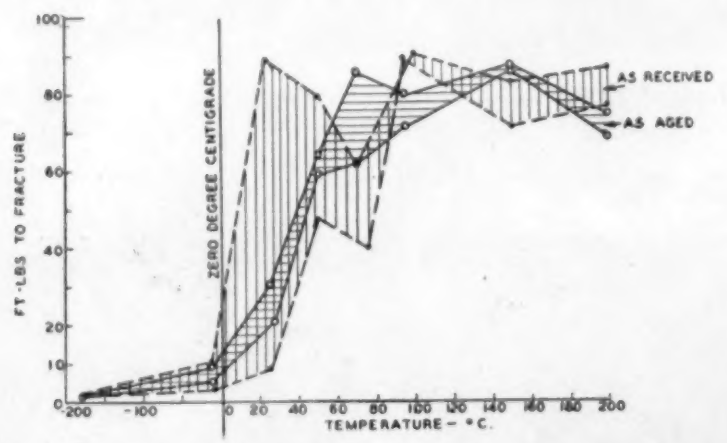


Fig. 14. The Effect of Temperature on the Impact Strength of all Weld Metal Deposited with Coated Electrode "F".

The experimental results are given in Figs. 12 to 14. As evident from Fig. 12 the amount of aging after cold deformation is not very pronounced in the bare wire weld W-F-A. The "as received" and "as aged" curves of this weld metal fall practically together. The impact values, however, are so low at room temperatures in the "as received" state that any effects of cold deformation in this range very likely will be marked by the much more pronounced effects of nitrogen embrittlement[8] due to the high nitrogen content in bare wire welds.

These curves are of interest however in that the transition range of the bare wire weld W-F-A is located at approximately 80°-100°C., while in the still more brittle sample #93 the transition zone is as high at 150°C.

In Fig. 13 the curves of the weld deposited with the coated wire W-98 are plotted. In this case the aging treatment had a definite affect upon the notch toughness. The drop in impact strength is shifted 40°C. towards higher temperatures. The impact strength at room temperature has dropped from approximately 45 ft.-lbs. to 17 ft.-lbs.* In the "as received" state this weld retains its toughness to quite low temperatures. At — 15°C. the impact strength is still above 20 ft.-lbs. It should be further noticed that there is very little scattering of the experimental points, a fact that confirms previous observations of the homogeneity of the W-98 material which was shown by the McQuaid-Ehn tests.

(Continued on page 256)

*Comparative results on Izett II boiler steel (containing approximately .15-.20% C) (F. R. Hensel: "Izett Steel," Westinghouse Research Memo. 60-7421-1) showed in the "as received" state in the temperature range of 0-100° C. an average impact strength of 105 ft.-lbs. The drop in notch toughness occurs at 0° C. where the impact strength is reduced to approximately 45 ft.-lbs.

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EDITORIAL COMMENT (Continued)

with the facilities and funds available, so that some of the topics merely represent fields in which different research groups are interested. And, of course, any such compilation is necessarily somewhat behind so that a good many of the projects listed have been completed, published and closed out, and some others unreported are active in their stead. However, the circular is without doubt a pretty good index of the subjects on which American metallurgists are actively seeking for new information.

Satisfaction with the present grade of ore is certainly not evident among the iron miners. Apparently they see much low grade iron ore and are seeking to bring it up to usable quality, for while flotation and other beneficiation methods on non-ferrous ores naturally lead in numbers of projects, there are a dozen or so listed that have to do with the beneficiation of iron ores.

Under development of test methods there are a few projects in metallurgical chemical analysis. Great interest is shown in non-destructive test methods such as radiography, magnetic and electrical resistance methods especially for welds, and in methods for determination of corrosion-resistance, wear-resistance, endurance and high temperature properties. Under the heading, properties of metals, study of the effect of high temperatures, corrosion-resistance, wear resistance and fatigue lead by a wide margin in the ferrous field. In the non-ferrous field, corrosion and study of die castings lead, with some attention being paid to bearing metals. Machineability is listed often enough to show its importance, and cast iron is mentioned so often as to indicate clearly the increased interest in this venerable material.

There is some little interest in the rarer metals, with three laboratories listed, working on extraction of beryllium beside some not listed.

Relatively few problems having to do with blast furnace practice or with metal smelting and melting are listed. Nor is the study of inclusions in steel mentioned as often as it would have been a few years ago. From the list, one would think that there was relatively little interest in rail steel or in deep drawing stock. The development of alloy steels, alloy cast irons, tool steels and the tungsten carbide type of tools is not mentioned often, probably because the private groups working along these lines did not report in detail.

Nitriding and electroplating also seem to be listed less often than one would expect. The work of several groups on the problem of low ductility in cast steel does not appear in the list.

The technical societies most active in metallurgical research are the American Society for Testing Materials and the American Society of Mechanical Engineers.

Of course, the work on many of the problems listed will not lead to any material and direct technical progress because many of them are undertaken primarily for educational purposes and the preparation of passable theses will close them up. But if the normal percentage do come out well, metallurgical progress will not lag.

The Bureau of Mines has performed a useful service in assembling this list, and the A.I.M.M.E. deserves credit for suggesting it.—H. W. Gillett

Reclaiming Leaky Castings

By W. M. CORSE*

PRODUCTION of castings to withstand either air pressure or water pressure is always attended with difficulty, and even today, after years of experimental work, a certain percentage of finished castings must be discarded.

These discards which add to the cost of good castings are known to the trade as "leakers," "weeps," or "sweats," but whatever the name they are anathema to the foundryman who would welcome a method of reclaiming them if the castings would stand the test of service after treatment.

The problem has increased in importance recently because of the introduction of new designs, and the growing demand for plumbing fixtures of corrosion-resistant and non-tarnishing alloys such as the white bronzes. As each change in design presents new problems, losses from "weeps" are likely to run anywhere from 10 to 75% on first runs, even when casting standard brass. Foundrymen felt, therefore, that Pelion was being piled on Ossa when the demand arose for pressure tight castings of new alloys in new designs.

The question of what to do about the "weeps" has come in for a good deal of discussion and the feeling has been growing that they might be salvaged to the advantage of all concerned.

The practice of salvaging "leakers" is not new. During the World War when rejections had a supremely important bearing on our national defense, the War Department approved a sealing treatment for reclaiming slightly imperfect castings somewhat similar to the one described in detail below, a treatment used satisfactorily in connection with aluminum crankcase castings for airplanes. About 20 years ago H. W. Gillett also reported excellent results in connection with experiments on aluminum intake manifolds conducted for one of our large automobile companies. So successful was the salvaging of castings with a compound of phenol formaldehyde resin (generally known as Bakelite) that not only "weeps" but all the intake manifolds for this particular purchaser were specified to be treated with the compound in order to make certain that they would be tight.

It is necessary to stress particularly the fact that the treatment under discussion will not strengthen castings. It will have no effect on their physical properties. Castings that must withstand certain specified stresses will be no stronger after treatment than before it, and attempts should not be made to reclaim castings with large imperfections or blow holes. The method is recommended only for salvaging "weeps" or "sweats."

The method used for salvaging imperfect castings is very simple. Phenol formaldehyde resin is dissolved in alcohol and the compound is then forced into the tiny intercrystalline pores under pressure until it shows on the outside of the casting. (Pressures between 200 and 300 lbs./in.^{2} are used.) After removing the excess varnish from the surface the casting is baked at a high temperature to polymerize or condense the compound thus changing it chemically and thereby producing an insoluble product in place of the initial soluble one; a product inert to caustic soda, washing soda, ordinary acids, hot water, etc.

There are several varieties of resinous products made from other chemicals that will react similarly to phenol and formaldehyde to form a condensation product which are in use for some of the manifold purposes to which Bakelite is put. Some of these in varnish form might be used for plugging leaks, but the details of their application for this purpose have apparently not yet been worked out, so our discussion has to be confined to the use of Bakelite.

There are two types of sealing solutions. One is made up without filler and the other contains a suspended inert filler. When reclaiming pressure castings of brass, bronze, nickel silver, and high shrinkage alloys where the leakage is caused by porosity, and the imperfections are extremely minute, a solution of phenol formaldehyde resin and alcohol without filler should be used. This solution can be forced into the smallest pores and hardened in place, and castings thus treated can be expected to give the same results as perfect castings in normal service.

When reclaiming castings of aluminum and aluminum alloys a solution containing inert filler suspended in phenol formaldehyde resin and alcohol is especially useful. The mixture should be sucked or forced through the leaks. When complicated shapes are being treated it is sometimes necessary first to evacuate and then to pressure treat to seal the leaks. When forced into comparatively large openings of imperfect aluminum castings such a solution will filter out the suspended material gradually building up a concentration of it inside the pore, much as a filter is built up by a chemist, until the suspended matter will not pass through. The voids among the particles of filler are, of course, filled with the solution, all of which hardens and bonds into one solid mass.

It is most essential that the proper compound be selected. One containing filler would be most objectionable if used on brass, bronze, white metal, etc., as the filler would clog the leaks at the casting surface and the sealing solution could not penetrate sufficiently. On the other hand, a compound without inert filler in solution would have no effect at all on the larger flaws of aluminum castings.

The question has been raised as to whether the difference in coefficient of expansion of the sealing compound and the metal of the casting will cause the leaks to open up. This is a remote contingency because the intercrystalline flaws are extremely irregular and very tiny. Castings treated with these solutions have been tested under various conditions and put back under pressure with entirely satisfactory results.

The most satisfactory method of application is to force the sealing compound through the pores from the inside. Small castings such as plumbing fixtures can be screwed onto a manifold, and plugs, pipe caps, etc., are used to close them off, or they may be placed in fixtures such as those generally used for hydrostatic testing. Faucets or pet cocks may be closed off by their own closing mechanism as the outlet disc of these fittings is not a pressure section. The solution is then forced into the casting under a minimum pressure of 250 lbs./in.^{2} maintained for approximately 30 minutes. Some comparatively large leakers have necessitated maintaining pressure for as much as 2 hours, but this is unusual. When the sealing compound no longer oozes through the pores the pressure is released, the casting drained, and then baked for at least ½ hour at a temperature ranging from 275° to 300° F. The exact time and temperature used will depend upon weight of casting and type of oven.

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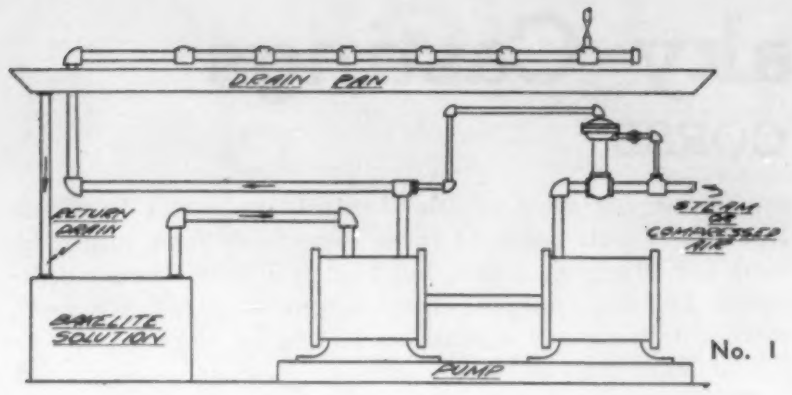
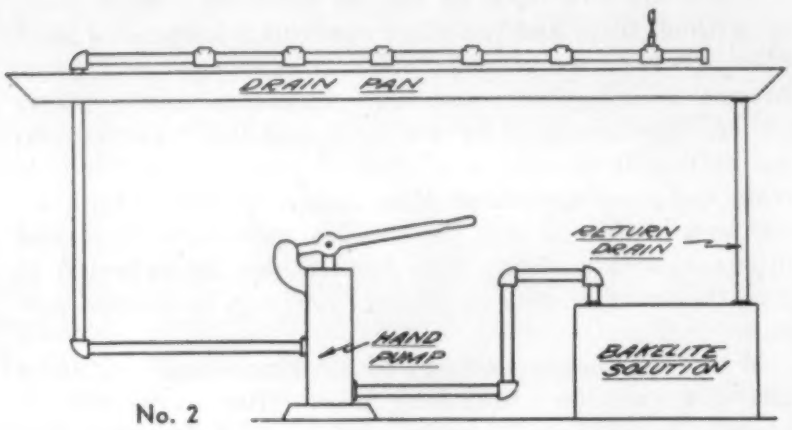
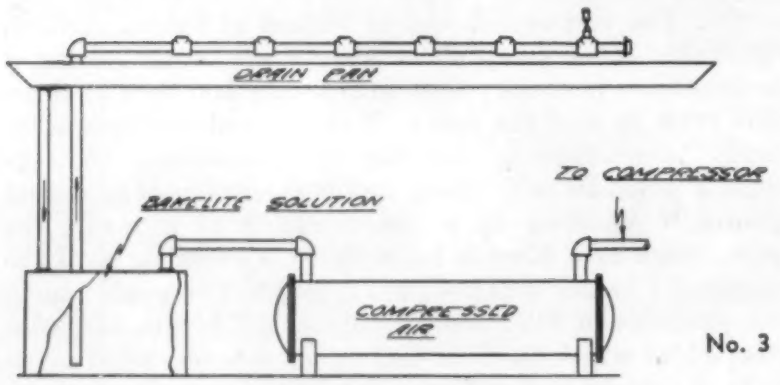


No. 1



No. 2



No. 3

The solution after baking is unaffected by hot and cold water, steam, and temperatures up to 400° F., and castings treated with the proper compound can be expected to last as long as sound castings, as long as they are subjected to normal use in fittings for compressed air, water, hot water, salt water, or steam. Special investigations should be made if it is planned to use reclaimed castings for handling chemicals. The treatment is not ordinarily recommended for castings in chemical equipment.

A comparison of 3 methods of treating defective castings with the idea of salvaging them was made. Three lots of alloy castings were tested in the laboratory of a large corporation for leaks. One lot was plugged with water glass, one with shellac, and one with a solution of phenol formaldehyde resin and alcohol. All of the castings were kept in a bath of continuously boiling water from the city water supply of Bloomfield, New Jersey. At the end of 100 hours all of the castings treated with water glass were leaking. After 312 hours the shellac treated castings all leaked, whereas the lot treated with phenol formaldehyde resin and alcohol were sound at the end of 10½ months and the test was being continued.

The apparatus used is simple and the cost is not prohibitive. There is required

1. A small hand pump for small or experimental installation.
2. A small plunger pump operated by steam or compressed air with a pressure regulator for constant pressure.
3. A two stage centrifugal pump or two small centrifugal pumps connected in series and motor operated, or
4. Compressed air.

No. 1 is the least expensive; No. 3 is the most expensive and No. 2 is most satisfactory all around.

The attached sketches show diagrammatic set-ups for three typical installations.

Sketch No. 1	Cost of pump.....	$200 to $250
	Total cost of installation not over	$500
Sketch No. 2	Cost of hand pump.....$60	(approximate)
	Total cost of installation not over	$150
Sketch No. 3	Cost of compressor regulator and storage tank about	$300
	Total cost of installation not over	$500

These equipment costs can be reduced materially by using parts usually found in the average maintenance shop. Labor outlay should be low, as no great skill is required for applying the sealing compound. Cost of material is low, as a gallon of the solution at a cost of approximately $2.70 will treat up to several thousand leakers, depending on their size.

In conclusion it should again be stressed that this treatment will not change the physical properties of castings; it will not strengthen them, and it should not be used when large imperfections or blow holes are present. It is recommended for salvaging "weeps" or "sweats" only.

◈ ◈ ◈

(Continued from page 254)

In Fig. 14 the curves for coated wire "F" are given. Here again no noticeable effect of the aging treatment was found. The drop in impact strength occurs at practically the same temperatures in the "as received" and the aged state. The fact that in the "as received" state the drop in impact strength occurs at or just below room temperature is important. The impact values at room temperature range from 8 to 89 ft.-lbs. This might also indicate that the welds had aged while standing at room temperature for approximately 3 months before testing. This point is being studied in more detail. At elevated temperatures the impact values of this material are very high, the average amounting to as much as 80 ft.-lbs.** Apparently there exist large variations in the notch toughness of welds which cannot be accounted for without considerable further study.

In conclusion the authors hope that this paper will stimulate more fundamental research work on the metallurgy of arc welding. They also want to thank Mr. D. L. Mathias and Mr. W. A. Maddox for their help in preparing this paper.

**For comparison it might be mentioned that the impact strength of ingot iron in the "as received" state amounts to approximately 80 ft.-lbs. if tested slightly above room temperature. (F. R. Hensel & T. F. Hengstenberg. Paper presented at *American Institute Mining & Metallurgical Engineers*, Buffalo meeting, 1932, *Technical Publication* No. 488, "Effect of Inclusion Streaks on the Tensile and Dynamic Properties of Wrought Iron and Similar Materials."

[1] Age Hardening Phenomena in Typical Fusion Weld Metal. *Transactions American Society for Steel Treating*, Vol. 19, 1932, pages 639-672.

A Study of the Transformation Points of Fusion Weld Metal. *Journal American Welding Society*, Vol. 11, Apr. 1932, pages 28-32.

Corrosion Apparatus Aids Study of Welds. *Electric Journal*, Vol. 29, Mar. 1932, page 149.

New Micropyrometer for Determining Melting Points of Welding Slags. *Electric Journal*, Vol. 29, Mar. 1932, page 152.

[2] L. W. Schuster. *Engineer*, Vol. 153, May 20, 1932, page 612.

[3] *Transactions American Institute Mining & Metallurgical Engineers*, Vol. 67, 1922, pages 341-391.

[4] *Stahl und Eisen*, Vol. 52, 1932, pages 236-239.

[5] *Stahl und Eisen*, Vol. 51, 1931, pages 1613-1616; *Metal Progress*, Vol. 18, Nov. 1930, page 33.

[6] See *Metals & Alloys*, Vol. 3, Mar. 1932, page 62, Izett Steel by G. G. Neuendorff: "At certain temperatures (especially around zero degrees centigrade for low carbon steels) every material has a transition zone from high to low values of notch toughness and in this zone the notch toughness depends upon a great variety of conditions, as for instance, structure, previous heat or mechanical treatment, dimensions of the specimens, shape of the notch, velocity of the impact, etc. In testing the aging properties by means of the notched bar impact test, the test conditions must therefore be always comparable."

[7] F. Körber & A. Pomp. *Mitteilungen Kaiser Wilhelm Institut für Eisenforschung*, 1925, pages 21-33.

E. Maurer & R. Mailänder. *Stahl und Eisen*, Vol. 45, 1925, page 409.

P. Dejean. *Revue de Métallurgie, Memoires*, Vol. 24, 1927, page 415.

S. R. Bolsover. *Journal Iron & Steel Institute*, Vol. 119, 1929, No. 1, page 473.

[8] *Transactions American Society for Steel Treating*, Vol. 19, 1932, pages 639-672.

The Resistance of Copper and Its Alloys to Repeated Stress

By H. W. Gillett*

Part III. The Brasses and Nickel-Brasses

AS has been brought out in Parts I and II of this summary,** the cold working of tough pitch copper only raises its endurance limit from 10,000 lbs./in.² to around 20,000 lbs./in.²; and the addition of small amounts of other elements, such as P, As and Sb only raises the endurance of annealed copper to say 15,000 lbs./in.² For uses where higher endurance limits are required, it is therefore logical to turn to copper alloys containing higher proportions of alloying element. Because of their static strength, the brasses are foremost in such a connection. However, in the fully annealed condition brasses from 60 Cu-40 Zn to 90 Cu-10 Zn, as well as the few nickel brasses (nickel silvers or German silvers) on which data are available, show endurance limits that in general run only from about 17,000 to not over 23,000 lbs./in.², except for one lot of 60:40 brass tested by Moore and Konzo[1] that showed 66,000 lbs./in.² tensile and 29,000 lbs./in.² endurance limit at 400 million cycles and another 60:40 tested by Kommers[2] of 76,500 lbs./in.² tensile and 27,500 lbs./in.² endurance limit at 50 million cycles. Cold working would be expected to raise the endurance.

Isemer[3] finds that threaded specimens of leaded 60:40 brass are slightly improved as to endurance by cold working the base of the threads. Behrens[4] finds that this material (initial condition not stated) has a life of 2 million cycles at 15,000 lbs./in.², which is raised to 18,000 by compressing the surface by working between rollers under pressure.

Severely cold worked material in this range of composition, with tensile strengths of 75,000 lbs./in.² up to almost 100,000 lbs./in.² likewise falls within the 17,000-23,000 lbs./in.² range of endurance values, except one tested by Moore and Jasper,[5] of 96,500 lbs./in.² tensile and 26,000 lbs./in.² endurance limit (500 million cycles). On giving the brasses a low-temperature stress-relieving anneal at around 500°F., not sufficient to lower the tensile strength, their endurance limits generally rise, though McAdam[6] gives data on one lot of 60:40 of 76,500 lbs./in.² tensile, after a 450°F. anneal, whose 100 million cycle endurance limit was only 16,000 lbs./in.², and on a 65:35,[7] given that anneal, which had a tensile strength of only 54,000 lbs./in.² and a 20 million cycle endurance of only 13,000 lbs./in.²; on the other hand, another of 82,500 lbs./in.² tensile showed a 25,000 lbs./in.² 40 million cycle endurance.

Kommers[2] found, in a survey of the brasses, that the stress-relieving anneal was quite generally effective.

All these tests were on rod and indicate that there is a strong probability that the brasses can be over-cold-worked, from the endurance point of view, and that internal stresses introduced by excessive cold-working, may be an important factor in endurance. Perhaps the samples that did not show good endurance properties after the low-temperature anneal were previously over-worked, not merely to such a point that internal stress was developed, but even to the point where actual or incipient internal rupture began.

McAdam[7] ascribes the low static and endurance properties of EB 4.5 as compared to EBA 4.5 (Nos. 1 and 2, Table 2) to more severe cold-work on the former before the low-temperature anneal. The same applies to DZA 4.25 and DZ 4.5 (Nos. 3 and 4, Table 3).

The work of Townsend and Greenall[8] on 65:35, 70:30 and on nickel brass sheet cold-worked up to 10 B&S numbers hard, giving material of 95,000 to 115,000 lbs./in.² tensile does not indicate any marked reversal in endurance properties on extreme cold-working. No stress-annealing tests are recorded. The stronger the material was in tension, the higher the actual endurance properties, though the fact that the endurance ratios fall off as more cold-work is performed indicates strongly that an adverse as well as a favorable factor is being introduced with increasing severity of cold-work, though the favorable factor is out-weighing the unfavorable. It is stated[9] that "it is believed that each metal and each combination of composition in a general type of metal has an optimum degree of cold-work above which no increase of fatigue strength is obtained and below which strengthening in varying degrees is obtainable."

It seems quite possible that different methods of cold-working, e.g., drawing to rod or wire and rolling to sheet may not produce the same result as to endurance properties or endurance ratio, even though the percentage reduction between anneals were identical in both cases. At least we cannot take any one figure for the endurance of a given composition of brass cold-worked to a given tensile strength and say that every other sample of the same composition and same tensile strength will show the same endurance. The endurance is probably very much affected by the mode of cold-working, by whether or not any incipient internal ruptures were formed in a prior stage of cold-working, and by the amount and nature of the internal stresses.

There is no reason to suppose that the better endurance figures so far recorded for cold-worked brasses, say 25,000-29,000 lbs./in.², might not be exceeded were a systematic study made of the best combination of composition, pass reduction in cold-working, annealing schedule and final stress-annealing with the specific object of developing a material more resistant to fatigue.

In a comparison of cold-working by drawing and by rolling, it would be difficult to make sure that the test section of the ordinary rotary beam specimen, made from rod, is in the same condition as the surface, but the scheme used by Shelton[10]† would permit using long specimens of wire or rod or tubing without reducing the section. A comparison of split heats, part of each heat being made into rod or tubing and part into sheet, using the same reduction between anneals, in each case, should throw light on the effect of different modes of working. The Bureau of Standards high-speed method should be applicable for the work on sheet.‡

The development of material of better endurance properties would be of value for certain problems not yet entirely satisfactorily solved.

A good deal of work, on which nothing has been published, has been carried out by refrigerator manufacturers and by the makers of the "sylphon" type of expansion bellows, on tubing and on formed bellows. As a rule this work has been with "vibratory tests" aimed to bring out the life at high stresses rather than to determine the endurance limit. In fact, in some designs the service stresses are so high that failure is expected to ensue after a couple of million cycles. With the scatter that is normally found in the endurance life at such high stresses, too early failure is likely to be met in some proportion of the bellows or tubing. Material of higher endurance limit would have a definite place in such applications.

Corrosion-Fatigue. Not much information is available on corrosion-fatigue of the brasses. Haigh[11] made some tests, run only to a small number of cycles, showing that ammonia reduced the endurance of naval brass and 60:40 brass, No. 8, Table 1, 21,000 lbs./in.², and No. 12, Table 2, 17,500 lbs./in.², both for only 1½ million cycles. McAdam[7] found that salt water or carbonate water reduced the endurance of a sample of 60:40 (No. 2, Table 1) from 23,000 to 17,000 lbs./in.² for 50 million cycles. Ludwik[12] found a similar reduction for 60:40 (No. 17, Table 1) from 25,000 to 17,000 lbs./in.² for 10 million cycles with sea water corrosion simultaneous with the endurance test. On several lots of 65:35 (Nos. 1-5, Table 2), running from 13,000 to 25,000 lbs./in.² endurance, McAdam found the salt water and carbonate water corrosion fatigue limits all to run about 12,000 lbs./in.² (The number of cycles in corrosion-fatigue tests were: No. 1, 40; No. 2, 50; No. 3, 30; No. 4, 60; and No. 5, 10 million cycles.)

On 70:30 (Table 3), No. 3 fell from 19,000 to 13,000 lbs./in.² (100 million cycles) in both fresh and salt water; No. 4 from 13,500 to 9,000 lbs./in.² (50 million cycles); and No. 5 from 14,000 to 12,500 lbs./in.² (60 million cycles) in salt water.

On 80:20 (Nos. 1 and 2, Table 4), they ran 15,000 to 14,000 lbs./in.², the regular endurance tests showing 21,000 and 17,000

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*Battelle Memorial Institute.

**Metals & Alloys*, Vol. 3, Sept. 1932, pages 201-205, Oct. 1932, pages 236-238.

†See Fig. 8, *Metals & Alloys*, Vol. 2, Feb. 1931, page 74.

‡See Part I, *Metals & Alloys*, Vol. 3, Sept. 1932, page 204.

TABLE 1. 60-40 TYPE NAVAL BRASS, MUNTZ METAL, ETC.

No.	Worker	Mark	Composition Cu	Zn	Sn	Fe	Pb	Condition	STATIC: Tensile Strength lbs/.in.²	Elong. %	Red. Area %	Charpy Impact ft.-lbs.	Hardness	ENDURANCE: Stress for 1 Million Cycles lbs/.in.²	Endurance Limit lbs/.in.²	No. Cycles Millions	Endurance Ratio	Notes
1	McAdam[6]	U	60.81	38.32	.35			Hot rolled	59,500	48	55½			.....	18,500	(50)	.31	
2	McAdam[7]	DWE4.5	62.28	37.03	.59	.08		450°F. 1 hr.	84,500	12½	40	10		38,000	23,000	(100)	.27	See text, corrosion-fatigue
3	McAdam[7]	DWE8.5	62.28	37.03	.59	.08		850°F. 1 hr.	53,500	55½	60½			28,000	20,000	(100)	.37	See
4	Haigh[11]		58.50	40.10	.50	.87			65,000	27	28			28,000 (2 million, axial)			....	text, corrosion-fatigue
5	Haigh[11]		58.50	40.10	.50	.87		Annealed	58,000	31	32			26,000 (2 million, axial)			....	
6	R. R. Moore[13]		61.20	38.27	.43		.10		68,000	27	53			30,000	21,000	(100)	.31	See text, notched
	Muntz Metal, etc.																	
7	Haigh[11]		58.0	41.2		.80			74,500	30	31			28,000 (2 million, axial)				
8	Haigh[11]		58.0	41.2		.80		Annealed	58,500	28	30			24,500 (2 million, axial)				See text, corrosion-fatigue
9	Kommers[3]		58.84	40.03	.01	.03	.09	As received	76,500	24	52		Rockwell 82	36,000	27,500	(50)	.36	
10	Kommers		58.84	40.03	.01	.03	.09	527°F.	73,300	31½	58		79	38,000	30,500	(50)	.42	
11	Kommers		58.84	40.03	.01	.03	.09	1300°F.	57,500	41	58		54	30,000	21,500	(50)	.37	
12	Kommers		58.84	40.03	.01	.03	.09	1300°F. and shortened 20%	68,500	29½	40		79	33,500	25,500	(35)[a]	.37	
13	McAdam[6]	BF4.8	59.65	40.11		.16	.20	480°F. 1 hr.	76,500	2	5			27,000	16,000	(100)	.21	See text, torsion
14	McAdam[6]	BF6.5	59.65	40.11		.16	.20	650°F. 1 hr.	79,000	14½	17			32,000	18,000	(100)	.23	See text, torsion
15	McAdam[6]	BF8.4	59.65	40.11		.16	.20	840°F. 1 hr.	65,500	34½	42½			30,000	18,000	(100)	.28	See text, torsion
16	von Heydekampf[20]		58	40-41½			2½-3	Not stated	62,500	25			Brinell		28,500	(?)	(.46?)	
17	Ludwik[12]		60	40				Not stated	57,000	48	69		84		25,000	(10)		See text, corrosion-fatigue and notched
18	Moore & Konzo[1]	103	60.25	39.61		.02	.02	1020°F.	66,000	48	40		90	41,000	29,000	(400)	.44	
19	Moore & Ver[14]		60	40				1000°F. ½ hr.	49,000	50	24		70	22,500	20,500	(34)	.42	See text, understressing
20	Moore & Lewis[19]		62	35.2			2.8		60,500	23	47		124	23,000	18,000	(100)	.30	See text, torsion
21	Crampton[22] Sheet		61.84	34.71		.05	3.41	Sheet 8 nos. hard #20 B&S	87,500	4	....		....	.....	19,000	(16)	.22	
22	Moore & Jasper[5]	105A	59.78	40.11		.03	.08	Annealed 1290°F.	54,000	56	61	30	72	28,000	22,000	(400)	.41	
23	Moore & Jasper	105B	59.78	40.11		.03	.08	Cold-drawn ¾" to ½"	96,500	13	52	19	179	40,000	26,000	(500)	.27	
	Effect of Lead																	
24	Gillett & Mack[17]		61.60	38.31		.03	.06	Cold-drawn, final reduction 16.3%	60,000	41	73			28,000	20,000	(50)	.33	
25	Gillett & Mack		61.54	37.89		.04	.53	Cold-drawn, final reduction 16.3%	59,000	39	66			31,000	23,000	(50)	.39	
26	Gillett & Mack		61.03	37.89		.03	1.58	Cold-drawn, final reduction 16.3%	58,000	38½	60			31,000	23,000	(20)	.40	
27	Gillett & Mack		59.88	37.78		.03	2.61	Cold-drawn, final reduction 16.3%	59,000	37½	53			29,000 to 32,000	21,000 to 24,000	(50)	.36-.41	
28	Gillett & Mack		59.40	37.14		.03	3.43	Cold-drawn, final reduction 16.3%	58,000	36½	50½			29,000 to 31,000	19,000 to 23,000	(50)	.33-.40	
	Aluminum Brass						*Al*											
29	Genders, etc.[21]		60	36.5			3.5	Chill cast in 1" diameter	85,000	12½	19		154		15,500[b]	(?)	(.18?)	

[a]Muntz metal fully annealed, shortened 20% by compression, then given 527°F. anneal, shows same endurance limit as without 527°F. anneal.

[b]Genders states that ordinary 70:30 compared to his aluminum brass, has only 9,000 lbs./in.² endurance, but gives no static properties for the chill cast 70:30, details of endurance test not given.

lbs./in.² on these samples. On 85:15 and on 90:9 and 1 Sn (Nos. 10-12, Table 4), the corrosion fatigue results in salt or carbonate water were practically the same as the endurance limits without corrosion, these being 15,500 20-25 million cycles, and 17,000 lbs./in.² (40 million) for the materials tested, the 90:9:1 showing the higher value. If the corrosion fatigue results can be interpreted as being chiefly influenced by composition rather than by the particular temper and anneal of the materials tested, it would appear that the brasses lower in zinc had a slight edge, in corrosion fatigue, over those of higher zinc content.

Corrosive conditions ranging from mild to severe have sometimes to be met in the bellows and refrigerator service referred to above, so that tests of these forms are often made with an effort to duplicate service conditions more or less closely as to both stress and corrosion. While no data are available on the results, it is understood that they often indicate 85:15 or 80:20 brass to be superior to copper, as would be expected from the regular endurance tests. Under some corrosion fatigue conditions, some makers find the 85:15 superior to 80:20. An alloy of 80% Cu, ¾% Si, 19¼% Zn is also sometimes considered better than straight 80:20, for bellows. Further data on materials for these classes of service would be desirable.

According to a sketchy account† of work at the National Physical Laboratory, as yet unpublished in detail, the N.P.L. has found indication that the endurance of mild steel, annealed copper and annealed brass is better in a vacuum than in air. The implication is that there may be some type of corrosion-fatigue operating in air. It will be necessary to have the full account of the work before any theoretical or practical conclusions can be drawn from this observation. A paper by Gough and Sopwith on "Atmospheric action as a factor in the fatigue of metals," scheduled to be presented to the British Institute of Metals at the September, 1932 meeting, will probably contain the details.

Notched Endurance. Very few tests have been made on brasses with notched endurance specimens. On 60:40 (Table 1, No. 6) R. R. Moore[13] found that a 60° notch .055" wide, .038" deep reduced the 100 million cycle endurance limit from 21,000 to 13,500 lbs./in.² and Ludwik[12] found (Table 1, No. 17) that a notch .02 mm deep, .05 mm. radius reduced the 10 million cycle endurance from 25,000 to 21,500. But on 70:30, he found (Table 3, Nos. 16, 17) that the notch did not reduce the endurance. It would be unsafe to accept Ludwik's conclusions without corroboration.

†Anon. The National Physical Laboratory. *Engineering*, Vol. 134, July 22, 1932, pages 102-103.

Torsional Endurance. Torsion endurance data are likewise scarce and inconsistent. McAdam's harder samples (Nos. 13 and 14, Table 1) with respective 55,000 and 50,000 lbs./in.² torsion test, 31° and 99° angle of twist, had, for 5 and 20 million cycles, 5,500 and 7,500 lbs./in.² torsion endurance limit. His softer sample (No. 15) with 65,500 lbs./in.² tensile, 45,500 lbs./in.² torsion and 125° angle of twist gave for 50 million cycles, the somewhat higher torsion endurance limit of 8,500 lbs./in.² But Moore and Ver[14] (Table 1, No. 19), working with material of not widely differing static properties from those of McAdam's softer sample, found 14,000 lbs./in.² for the torsion endurance limit. The rotating beam endurance limit for both materials was the same, 18,000 lbs./in.²

On cold-rolled 70:30 (Table 3, No. 2) with 47,500 lbs./in.² tensile and 41,000 lbs./in.² torsion, and with 575° angle of twist, McAdam found a 40 million cycle torsion endurance limit of 9,000 lbs./in.² Tested in the as-received condition, the static properties indicate that this must have been annealed or had little final cold-work, so, in the absence of rotary beam tests for exactly analogous material, the relation between rotary beam and torsion endurance values cannot be calculated.

On nickel brass there is only one torsion test on record, that of McAdam[6] (Table 4, No. 14). This annealed alloy, showing 44,000 lbs./in.² in torsion test and 857° angle of twist, had 13,000 lbs./in.² (number of cycles not stated) torsion endurance limit. The scanty data on endurance in torsion would indicate that over-cold-working might be especially detrimental in torsion, since the torsion endurance tends to be higher on the softer materials.

Axial Loading. Outside of the early tests of Haigh,[11] of too short duration to be useful for comparison, the only axial loading test is that of Tapsell (Table 3, No. 11) and this was carried to but 10 million cycles. By comparison with McAdam's sample CJ (Table 3, No. 1), the endurance ratios indicate no notable effect due to axial versus rotary beam loading, but different samples tested by different workers are not very satisfactory for such a comparison.

Speed Effect. According to Lehr,[15] a hard drawn brass of 67,000 lbs./in.² tensile, 13% elongation showed a 10 million cycle endurance of 22,500 lbs./in.² in rotary beam test at 3,000 cycles/min., but when tested in a very high speed (30,000 cycles/min.) axial loading machine, it gave 37,000 lbs./in.² (also 10 million cycles). This would give an endurance ratio of 0.55,

TABLE 2. 65:35 TYPE

									STATIC				ENDURANCE				
			Composition														
No.	Worker	Mark	Cu	Zn	Sn	Fe	Pb	Condition	Tensile Strength lbs./in.²	Elong. %	Red. Area %	Charpy Impact ft.-lbs.	Stress for 1 Million Cycles lbs./in.²	Endurance Limit lbs./in.²	No. Cycles Millions	Endurance Ratio	Notes
1	McAdam[6]	EB4.5	65.14	34.73	....	.08	....	450°F. 3 hrs.	54,000	42½	66½	30	27,000	13,000	(20)	.24	See text, corrosion-fatigue
2	McAdam	EBA4.5	65.14	34.73	....	.08	....	450°F. 3 hrs.	71,000	22	58½	22	27,000	17,000	(5)	(.24?)	See text, corrosion-fatigue
3	McAdam	EB12	65.14	34.73	....	.08	....	1200°F. 1 hr.	43,500	77½	73½	39½	19,000	15,000	(20)	.34	See text, corrosion-fatigue
4	McAdam	EG4.5	64.95	35.06	....	.04	....	450°F. 3 hrs.	82,500	15	61½	10½	34,000	25,000	(40)	.30	See text, corrosion-fatigue
5	McAdam	EG12	64.95	35.06	....	.04	....	1200°F. 1 hr.	47,000	71	73	34	22,000	18,000	(10)	(.38?)	See text, corrosion-fatigue
6	McAdam		....	34.6	....	....	....	Cold rolled	55,000	34	58½	19	.....	23,500	(11)	(.43?)	See text, corrosion-fatigue
7	Hatfield[23]		....	34.6	....	....	....	1100°F. 2 hrs.	45,000	72	70	38	.....	13,500	(11)	(.30?)	See text, corrosion-fatigue
	Sheet																
8	Crampton[22] 20 B&S gage		67.87	32.13	....	.01	....	8 Nos. hard	90,000	4	....	....	.....	20,000	(16)	(.18?)	
9	Townsend & Greenall[8] 24 B&S gage		65.09	34.86	....	.03	.02	1110°F.	46,000	58	....	....	16,000*	14,000**	(100)	.30	
10	Townsend & Greenall 24 B&S gage		65.09	34.86	....	.03	.02	4 Nos. hard	77,000	6	....	....	22,000*	19,000**	(100)	.25	
11	Townsend & Greenall 24 B&S gage		65.09	34.86	....	.03	.02	10 Nos. hard	95,500	2	....	....	24,000*	21,500**	(100)	.23	
	Alpha Naval (Rod)																
12	Haigh[11]		66.3	32.2	1.20		.025		52,000	28	30	....	19,500 (2 Million, axial)				See text, corrosion-fatigue

*From published curves.
**These endurance limits, higher than those published, have been corrected by personal communication from Mr. Townsend.

very high for such material. As previously pointed out* in most high speed tests on record, the accuracy of the stress measurements is seriously in question.

On the other hand, the preliminary work of the Bureau of Standards** (Table 3, No. 23) gives an endurance figure and an endurance ratio on high speed test quite consistent with the data of Townsend and of Crampton (Table 3, Nos. 20-22, 24-25) for tests at normal speeds.

Accelerated Test Methods. The subject of accelerated test methods has been sufficiently dealt with in Parts I and II.* The results of Ludwik and Scheu[12] on 70:30 brass showed that accelerated test methods (deflection, rise of temperature and energy-input) all indicated results lower than the actual endurance tests.

*Parts I and II, *Metals & Alloys*, Vol. 3, Sept. 1932, page 204; Oct. 1932, page 236.
**Part I, *Metals & Alloys*, Vol. 3, Sept. 1932, page 204.

Understressing. Moore and Ver[14] (See Table 1, No. 19) report that after stressing a specimen at 20,500 lbs./in.^{2} for 7 million cycles and testing it in tension so that it elongated 11%, the reduction of area at that period in the test, before fracture, was 9.7% for material that had been under endurance test as above, and 10.2% for material that had not, showing hardening by under-stressing.

Schwinning and Strobel[16] find (Table 3, No. 19) that, on tensile test, after stressing for 200,000 cycles at 12,000 lbs./in.^{2} in the endurance test, the elastic limit and yield point rise over those for virgin material.

Gillett and Mack[17] did not find strengthening by understressing on the 60:40 and leaded 60:40.

Aitchison[18] found that a 68 Brinell 70:30 brass, properties not stated, stressed 40,000 cycles at 4, 5, 6 and 7 tons, then tested at 8 tons on the Haigh machine, broke after 2 million cycles, its Brinell rising to 98. Another specimen originally

TABLE 3. 70:30 AND 75:25 TYPES

No.	Worker	Mark	Composition Cu	Zn	Fe	Pb	Condition	STATIC: Tensile Strength lbs./in.^{2}	Elong. %	Red. Area %	Charpy Impact ft.-lbs.	Hardness	ENDURANCE: Stress for 1 Million Cycles lbs./in^2.	Endurance Limit lbs./in^2.	No. Cycles	Endurance Ratio	Notes
1	McAdam[6]	CJ	73.28	26.61	.13	.03	Cold-drawn as received (?)	50,500	57	73			30,000	17,000	(20)	.34	
2	McAdam	BP	71.64	28.24	.13	.02	Cold-rolled as received (?)	47,500	63½	74½			.....	.....	---	....	See text, torsion
3	McAdam[7]	DZA4.25	70.79	29.12	.07	....	425°F. 3 hrs.	76,500	18½	57½	18½		29,000	19,000	(70)	.25	See text, corrosion fatigue
4	McAdam	DZ4.5	70.79	29.12	.07	....	450°F. 3 hrs.	58,500	40½	67½	28½		27,000	13,500	(30)	.23	See text, corrosion fatigue
5	McAdam	DZ12	70.79	29.12	.07	....	1200°F. 1 hr.	45,000	75	74	41		16,000	14,000	(80)	.31	See text, corrosion fatigue
6	McAdam	DM	70.08	29.99	.05	....	Cold-rolled as received	73,000	20	46½	14		27,000	17,000	(100)	.23	
7	McAdam	DM4	70.08	29.99	.05	....	400°F. 1½ hrs.	74,500	15	41½	15½			20,000	(100)	.27	
8	McAdam	DM4.5	70.08	29.99	.05	....	450°F. 1½ hrs.	74,000	18	47½	16			20,000	(80)	.27	
9	McAdam	DM5	70.08	29.99	.05	....	500°F. 1½ hrs.	73,500	17½	48½			27,000	22,000	(70)	.30	
10	McAdam	DM12	70.08	29.99	.05	....	1200°F. 1 hr.	45,000	72½	66	37		22,000	15,000	(100)	.33	
11	Tapsell[24]		---	27.5	....	....	As received (?)	54,000	....	....	....	Rockwell B	.....	19,000	(10)	(.35?)	Axial (Haigh machine)
12	Kommers[2]		70.03	29.92	.02	.02	As received	74,000	20½	57½	....	81	30,500	22,000	(50)	.30	
13	Kommers		70.03	29.92	.02	.02	527°F.	73,500	23	60	....	81½	35,500	28,000	(50)	.38	
14	Kommers		70.03	29.92	.02	.02	1100°F.	47,000	55	75	....	11	25,000	22,500	(50)	.48	
15	Kommers		70.03	29.92	.02	.02	1100°F. then shortened 20% then 527°F.	51,500	58	70½	....	62½	28,500	25,000	(50)	.48	
16	Ludwik[13]	MS70	70	....	....	....	Annealed	48,500	56½	69½	....			20,000	(10)	(.41?)	See text, notched
17	Ludwik	MS70	70	....	....	....	Same, stretched 20%	53,000	43½	71	....			22,500	(10)	(.42?)	See text, notched
18	Gough[25]	BIF1	69.85	30.11	.04	....		44,500	84	85	....			20,000	(60)	.45	
19	Schwinning & Strobel[16]	5 mm. diam. wire	72	....	....	....	Annealed 1470°F.	38,500	55	81	....		23,500	12,000	(20)	.31	
	Sheet																
20	Townsend & Greenall[8] #24 B&S gage 0.02" thick	G	70.5-73.5	bal.	.05 max.	.10 max.	Annealed	46,500	61	....	....		19,000*	13,000**	(4)	.28	
21	Townsend & Greenall #24 B&S gage 0.02" thick	G	70.5-73.5	bal.	.05 max.	.10 max.	4 Nos. hard	81,500	6	....	....		25,000*	18,500**	(100)	.23	
22	Townsend & Greenall #24 B&S gage 0.02" thick	G	70.5-73.5	bal.	.05 max.	.10 max.	10 Nos. hard	98,000	2	....	....		27,000*	19,000**	(100)	.19	
23	Bureau of Standards[26] ⅛" Sheet		---	26.7	....	....	Hard	91,000	8	....	....		.....	18,000±	(75)	.20	High speed machine
24	Crampton[22] #20 B&S gage		71.36	27.55	.01	.08	8 Nos. hard	98,000	3	....	....		.....	21,000	(20)	.22	
25	Crampton #20 B&S gage		71.36	27.55	.01	.08	475°F. anneal	99,000	3	....	....		.....	23,000	(20)	.23	
	Aluminum Brass and Chill Cast 70:30				*Al*												
26	Genders, etc.[21]		70	30			Chill cast 1" diam.							9,000	(?)	....	
27	Genders, etc.		70	26.6	3.4		Chill cast 1" diam.	74,000	33	33	....			22,500	(?)	....	

*From published curves.
**These endurance limits, not differing much from those published, have been corrected by personal communication from Mr. Townsend.

stressed at 7 tons, broke in 14 million, with similar increase in hardness, and copper, properties not stated, originally 52 Brinell, at 4¾ tons, broke in 6½ million, hardness rising to 75.

The effect of under-stressing on brasses is now being experimentally studied by Professor Kommers of the University of Wisconsin.

Effect of Lead. The effect of lead is not clear. Moore and Lewis[19] (Table 1, No. 20) and von Heydekampf[20] (Table 1, No. 16), each working on metal with about 3% lead, and of about the same static properties, report endurance limits of 28,500 and 18,000, which bracket the figures for lead-free material of similar static properties, while Gillett and Mack[17] (Table 1, Nos. 24-28) in a series in which the Cu:Zn ratio is held constant and the lead varied, show no clear effect ascribable to lead.

Cast Material. This group of alloys is not much used in the cast condition, and the only data on record are those of Genders,[21] on chill cast specimens of a single aluminum brass.

Lack of Data. No data were found on 90:10 and only one set of data each (Table 4, Nos. 12 and 21) for that type of alloy with Sn or P. Nothing at all was found on 95:5 or other commercial alloys of low zinc content.

There is a marked scarcity of data on nickel brass. No data on corrosion fatigue, on effect of notches, on under-stressing or on sand cast alloys, are available. Only one torsion fatigue figure is on record. Insufficient data are available to tell the specific effect of changes in Zn and Ni content. The data for rod and sheet are not on comparable compositions. The data on sheet indicate that endurance tends to rise with cold-working, but the corrected data of Townsend and Greenall (Table 4, Nos. 17-19) show that with extreme cold-work, the endurance limit of sheet may fall somewhat, and it might turn out that rod was even more susceptible to such an effect than sheet.

TABLE 4. 80:20, 85:15, 90:10 AND NICKEL BRASS TYPES

No.	Worker	Mark	Composition Cu	Ni	Zn	Fe	Pb	Misc.	Condition	STATIC: Tensile Strength lbs./in.²	Elong. %	Red. Area %	Charpy Impact ft.-lbs.	Hardness	ENDURANCE: Stress for 1 Million Cycles lbs./in.²	Endurance Limit lbs./in.²	No. Cycles Millions	Endurance Ratio	Notes
	80:20 Brass																		
1	McAdam[6]	HY4.5	79.40	.....	20.50	.10	....	....	Cold-drawn 450°F. 2 hrs.	58,000	30½	64½	23		26,000	21,000	(100)	.36	See text, corrosion-fatigue
2	McAdam	HY9	79.40	.....	20.50	.10	....	....	900°F. 2 hrs.	45,500	62	72	41		22,000	17,000	(40)	.37	See text, corrosion-fatigue
3	Kommers[2]		79.51	.....	20.28	.02	.09	....	Cold-rolled as received	72,500	18	61	—	Rockwell B 81	28,000	21,500	(50)	.30	
4	Kommers		79.51	.....	20.28	.02	.09	....	527°F.	70,500	22	64½	—	80½	34,000	25,000	(50)	.35	
5	Kommers		79.51	.....	20.28	.02	.09	....	1100°F.	45,500	51	73	—	17	23,500	22,500	(50)	.50	
6	Kommers		79.51	.....	20.28	.02	.09	....	1100°F. and shortened 20%	48,500	51	72½	—	67	31,000	25,500	(50)	.53	
7	McAdam[6]	DN	81.0	.....	19.06	tr	....	....	Cold-drawn as received	76,500	16	65	26		27,000	22,500	(100)	.29	
8	McAdam	DN4.5	81.0	.....	19.06	tr	....	....	450°F. 1 hr.	80,500	15	64	....		32,000±	26,000	(40)	.32	
9	McAdam	DN10	81.0	.....	19.06	tr	....	....	1000°F. 1 hr.	44,000	64	80	27		21,000	17,000	(90)	.39	
	85:15 Brass																		
10	McAdam[6]	HX4.5	84.91	.....	15.04	.05	....	....	Cold-drawn 450°F. 3 hrs.	53,000	27	73	31		26,000	16,000	(60)	.30	See text, corrosion-fatigue
11	McAdam	HX9	84.91	.....	15.04	.05	....	....	900°F. 3 hrs.	40,500	57	79	47½		17,500	15,500	(100)	.38	See text, corrosion-fatigue
	90:10 Brass							*Sn*											
12	McAdam[6]	HYA (Tin)	90.75	.....	8.62	.13	....	1.10	900°F. 3 hrs.	49,000	62	75½	38½		25,000±	16,000	(60)	.33	See text, corrosion-fatigue
	Nickel Brass							*Mn*											
13	McAdam[6]	CD	74.01	19.75	5.17	.34	....	.75	Hot-rolled	57,000	36	70	——		30,000±	23,000	(60)	.40	
14	McAdam	CD1	74.01	19.75	5.17	.34	....	.75	1400°F. 1 hr.	51,000	47½	72½	——		.....	.....	....		See text, torsion
15	McAdam	CG	60.08	10.89	29.05	.20	....	....	Cold-drawn as received[a]	58,500	49½	59	.....		33,000±	17,000	(60)	.29	
16	McAdam	CH	65.30	17.63	17.15	.23	....	....	Cold-drawn as received[a]	62,500	28	49½	.....		28,000	22,000	(50)	.35	
	Sheet																		
17	Townsend & Greenall[3] 24 B&S Gage 0.02" Thick		53.5-56.5	16.5-19.5	25.5-28.5	.35 max.	.01 max.	.05 max.	Annealed	67,000	42	.....	.....		23,000*	17,000**	(100)	.25	
18	24 B&S Gage 0.02" Thick		53.5-56.5	16.5-19.5	25.5-28.5	.35 max.	.01 max.	.05 max.	4 nos. hard	98,500	2	.....	.....		26,000*	22,000**	(100)	.22	
19	24 B&S Gage 0.02" Thick		53.5-56.5	16.5-19.5	25.5-28.5	.35 max.	.01 max.	.05 max.	10 nos. hard	116,000	1½	.....	.....		35,000*	21,500**	(100)	.19	
	Sheet 80:20 and 90:10																		
20	Crampton[22] No. 20 B&S Gage 80:20		79.76	.....	20.23	.01	....	....	8 nos. hard	90,500	4	.....	.....		.....	24,000	(16)	(.26?)	
21	Crampton[22] No. 20 B&S Gage 90:10 (Phos.)		89.84	.....	10.12	....	....	*P* .04	8 nos. hard	71,500	4	.....	.....		.....	21,500	(16)	(.30?)	

[a]McAdam tabulates values for endurance limits of CG and CH annealed, but states that these are assumed by analogy with the as-received figures; so they are not tabulated here.
*From published curves.
**These endurance limits, not differing much from those published, have been corrected by personal communication from Mr. Townsend.

Summary. The wrought brasses and nickel brasses of commerce are as a rule stronger in endurance under repeated stress than is copper, but tend to be more affected by corrosion-fatigue. The higher the copper content, the better the corrosion-fatigue properties appear. Unfortunately, data are lacking on corrosion-fatigue of the nickel brasses.

There are strong indications that the brasses and nickel brasses, like copper, can be over-cold-worked, and that proper choice of compositions, avoidance of setting up incipient cracks in cold-working, and the use of a final stress-relieving anneal, might produce material of decidedly better and more reliable endurance properties than is yet available. The work of Kommers[2] is especially interesting in this connection. That of Pilling,[27] though on another material, also shows interesting analogies.

These alloys are somewhat subject to damage of notches or other stress-raisers, and it may be that their torsion fatigue properties are lower than would be expected from the ratio of rotary bending and torsion endurance limits on other alloys.

There is a need for better material for tubing and for bellows of the sylphon type and systematic study, aimed particularly at these problems, would be helpful.

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READERS' COMMENTS

Editor, METALS & ALLOYS:

In connection with the article on fatigue of copper, page 202, of the September issue, on the pros and cons of annealing copper tubes used for oil and gas lines, we have some fatigue data which may help clear the atmosphere on this point. Our test data would at least lead to the following tentative conclusions:

(1)—If the tubing is annealed after forming and is not subsequently reformed, it need not be re-annealed during its useful life.

(2)—If the tubing is reformed extensively, at any time after its final annealing, it should be again re-annealed after such forming.

(3)—Any gas or oil lines made from hard drawn tubing would probably show better fatigue life if the bends were partially annealed.

(4)—Hard drawn tubing installations involving service conditions wherein nicks or scratches or similar stress raisers occur (especially during assemblies and disassemblies) would probably show increased fatigue life if partially annealed shortly after such stress raisers occur. Greater precautions have to be taken with hard drawn tubing installations in preventing nicks, scratches, etc., than in the case of annealed tubing.

The above conclusions are based on the results of fatigue tests which we have carried out on both annealed and hard worked material using "V" notch type of specimen. These results indicate very definitely that the notches have proportionally much greater deleterious effects in the case of hard worked material than they do in the case of annealed material (see table).

Yours very truly,

Aluminum Company of America	R. L. TEMPLIN Chief Eng'r of Tests
Sept. 19, 1932	Aluminum Research Laboratories

Effects of Notches on Endurance Limit of Annealed vs. Cold Worked Metal

	Endurance Limit lbs./in.^{2}			
Type of Notch	Alloy A* Annealed	Alloy A 60% Reduction by Cold Working	Alloy B* Annealed	Alloy B* 60% Reduction by Cold Working
None	14,000	15,000	19,000	21,000
60° Sharp V	4,000	2,500	6,000	2,500
Reduction Caused by Notch	71%	83%	68%	88%

*Alloys A and B are experimental alloys.

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Editor of METALS & ALLOYS:

I would like to make a few comments on Mr. J. R. Vilella's paper published in your September issue.

Mr. Vilella is to be complimented on the manner in which he has illustrated the correct polishing procedure. As Mr. Vilella suggested, the method itself is not new, however, its application to cast iron is new in that it shows the actual graphite structure. Further, I am glad to see that his work confirms that of Mr. Schneidewind and myself on the same subject, which was published in the August issue of "Metal Progress."

I would like to give some additional evidence which Mr. Schneidewind and I have obtained as a more rigorous proof that the usual polishing procedure is incorrect.

In our work at the University, we used a micromanipulator that is attached to the stage of the microscope. With this setup it is possible to make a series of scratches on samples polished both ways. These experiments were made by passing a fine metal needle over the polished surface of the specimen and observing its motion in the microscope. Whenever the needle passed over one of the black areas, it could be readily observed that the needle actually dropped into a void. Following the same procedure on specimens polished by the new method, it is clearly seen that the gray areas are actually fragmented, leaving a broad trace in the path of the needle. From this observation it is concluded that the black areas formerly designated as graphite are voids formed by the tearing away of the graphite during the polishing operation.

To further confirm the above contention, samples of Acheson graphite were polished according to the new procedure. These were compared with the gray areas in cast iron. The structures observed are identical when viewed in either the ordinary

(Continued on page MA 325)